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MARINE EARLY PERMIAN OF THE CENTRAL ANDES AND ITS FUSULINE FAUNAS.

PART II.

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DESCRIPTION OF SPECIES.

Schwagerina prolongada (Berry)

Plate 1, figs. 1-11.

Schellwienia convoluta Meyer. Neues Jahrb. für Min., Geol., u. Pal., Beil. Bd., vol. 37, 1914, p. 598, pl. 14, fig. 1.
usulina prolongada Berry. Pan-American Geologist, vol. 49, 1933, p. 271, pl. 22, figs. 1, 5, 11.

Description.—A slender, subcylindrical species attaining a ıngth of 10 to 12 mm. and a diameter of 1.9 to 2.0 with 7 to 8 losely coiled volutions. Young shells have a slender fusiform hape and a form ratio of 2:1 up to 4:1, but as they approach ıaturity they assume a subcylindrical shape with bluntly ounded poles and the form ratio rises to about 6:1. The ntetheca is low except near the poles, and is strongly and egularly fluted along its basal margin while remaining nearly lane near the upper or outer edge.

The prolocula commonly range between 135 and 175 microns ı diameter and are generally subspherical and thin walled. In he equatorial region the whorls are very low and the expansion radual.

The spiral wall is rather thin, increasing gradually from 5 to 20 microns in the first volution to 80 or 90 microns in he sixth. Its structure is commonly obscure in the first 2 or 3 horls but shows a distinct tectum and keriotheca in the outer olutions.

The septa are regularly folded from pole to pole but in axial ections the septal loops appear short because the folds are ırgely confined to the lower or proximal half of each septum.

Tangential slices (Fig. 4 of Plate 1) show well this peculiarity. The tunnel is wide, and in the first 4 or 5 volutions is bordered by very narrow, low chomata. A slender zone of axial filling follows the axis.

TABLE OF MEASUREMENTS.*

Whorls	Half length #1	2	3	4	Radius vector #1	2	3	4	Form ratio #1	2	3
0	.05	.10	.07	.093	.05	.10	.07	.093	1.0	...	...
1	.25	.35	.23	.29	.12	.15	.13	.14	2.0	2.3	1.7
2	.45	.70	.50	.50	.18	.21	.19	.19	2.5	3.3	2.6
3	.70	1.03	.90	.75	.25	.28	.26	.26	2.8	4.0	3.5
4	1.00	1.70	1.25	1.00	.33	.40	.37	.36	3.0	4.2	3.3
5	1.70	2.50	2.00	1.80	.45	.59	.49	.50	3.5	4.2	4.1
6	2.70	4.20	3.90	3.00	.60	.77	.70	.64	4.5	5.5	5.6
7	4.30	...	5.70	5.00	.80	...	.94	.86	5.4	...	6.1
8	5.90	...	...	...	1.00	...	...	1.08	5.9	...	...

Whorls	Tunnel angle #1	2	3	4	Wall thickness #1	2	3	4	Septal coun. #5	6	7
0	...	...	...	...	...	.020	.015	.015	...	...	...
1	...	...	...	...	...	.015	.020	.015	...	...	...
2	...	40°	...	20°	...	.020	.020	.025	17	16	12
3	27°	43°	36°	28°	...	.025	.020	.030	17	17	14
4	35°	48°	41°	36°	...	.035	.025	.036	18	19	16
5	38°	48°	50°	45°	...	.060	.043	.043	24	20	...
6	...	55°	45°	48°	...	.070	.070	.070	25	29	...
7	56°	...	...	58°	...	...	...	.070	...	...	...

Specimens 1 to 6 are illustrated on Plate 1 as Figs. 1, 3, 8, 9, 10, and 11, respectively.

Discussion.—This species is very similar to *S. linearis* Dunbar and Skinner of the Wolfcamp strata of Texas, which it resembles in shape and size, in the form of its low septal folds, in the width of its tunnel, and in its secondary axial filling. Indeed, the distinction can hardly be more than varietal. In the Texas shells the prolocula are commonly much larger than in the South American form and have even thinner walls.

The original description and illustration of *Fusulina prolongada* Willard Berry would hardly permit recognition of the

* In this and following tables of measurements, data for several types are arranged for easy comparison. Specimens are numbered from left to right across each unit of the table and whorls are numbered from the top downward along the left side of the table, the proloculum being designated as zero.

species, but through the kindne[illegible] f Professor Edward W. Berry we have been able to res[illegible] [illegible]e types. The axial section shown as figure 1 on Berry's [illegible] is reproduced from a new photograph at the standard magr[illegible]fication of 10 diameters as Fig. 1 of our Plate 1. This we designate as the holotype specimen. It has been used along with some 50 other sections in drawing up the description given above.

This is probably the species described by Meyer as *Schellwienia convoluta* and we intended at first to use his specific name, but critical study of his description and illustration have persuaded us that such a course is not justified. Meyer stated that he had only a few individuals, that they were embedded in matrix, and that they were badly broken. He gave only a single figure which represents the inner whorls of an incomplete axial section. It is apparently a drawing rather crudely made and the magnification is not indicated. The significant part of his description may be translated freely as follows:

"The dimensions of the largest individual are 12 mm. in length by 2.8 mm. in diameter, the ratio being 6:1. This is a very high ratio. In the early volutions it is not so great, being only 2.6:1 in the third volution of the figured specimen. The form is still pointed at the ends in the early whorls, later becoming cylindrical. The diameter of the single observed proloculum is 0.15 mm.

"The coiling is extraordinarily close so that the four first volutions in the figured specimen attain a diameter of only 0.6 mm. The number of volutions runs up to 7. The thickness of the wall in the last volution is 0.055 mm."

This statement bears evidence of inexcusable carelessness and inaccuracy. If the length be 12 and the diameter 2.8 mm., then the ratio is not 6:1 but about 4.3:1. [The diameter probably was 1.8 instead of 2.8 mm.] Furthermore, the stated dimensions indicate that the diameter of the proloculum is exactly one fourth that of the fourth volution, whereas the figure shows it to be almost exactly one third. Since the actual scale of the figure is not indicated, the dimensions cannot be checked. On Meyer's plate there are figures of two other fusulines, and of brachiopods, a bryozoan, and a coral. At least five different magnifications are used on this plate and the scale is indicated for all but two of the figures, that of *Schellwienia convoluta* and one of another fusuline, *S.* aff. *vulgaris*. Two figures of

another fusuline, *Schellwienia peruana*, are shown to be at 16 diameters. If we accept the stated dimensions of the proloculum, the figure of *S. convoluta* is enlarged to ±13.3 diameters; but if we accept the stated diameter of the fourth volution the enlargement is at ±11.3 diameters. On the assumption that the enlargement was to 16 diameters, we have reduced Meyer's figure to a X 10 enlargement and reproduced it as our Fig. 5 of Plate 1. Thus it corresponds rather closely in shape and dimensions with the inner volutions of *S. prolongada* Berry. On the contrary, detailed comparison of the shape of the septal loops and especially of the distribution of secondary filling, shows little resemblance. Actually, the strongest reason for suspecting that *Schellwienia convoluta* Meyer is the same as *Fusulina prolongada* Berry lies in the fact that Meyer's types came from Morochata, about 42 km. northwest of Cochabamba and that in our several collections from this general area *Schwagerina prolongada* (Berry) occurs abundantly and that it is the only species we have found with which *S. convoluta* could be compared.

Distribution.—Berry's types were stated to be from Chulpapampa and Yampupata, Bolivia. The species is abundant in Kozlowski's collections 8, 9, 12, 13, 15, and 16 about Apillapampa, Bolivia, and in Ahlfeld's collection 4 from the same section; it occurs also in Kozlowski's collection 3 at Yaurichambi and in Ahlfeld's collection 1 at Abra de Patapatani (between Achacachi and Chuchulaya) east of Lake Titicaca and in his collection 3 at Finca Chacapaya in the Cochabamba Basin. It is abundant in Newell's collection 139 near Tiquina; it is rare in Newell's collection 92 of the section at Muñani, Peru.

Schwagerina steinmanni Dunbar and Newell, n. sp.

Plate 2, figs. 1-10.

Description.—An elongate fusiform species of 7 to 8 volutions, attaining at 8 volutions a length of 10.5 to 12.0 mm. and a diameter of 2.2—2.4 mm. The lateral slopes are gently convex and the poles bluntly rounded. The antetheca is lowest at the middle, increasing in height toward the poles, and is deeply and regularly folded throughout.

The prolocula are rather small, ranging between 120 and 200 microns in diameter. They are commonly subspherical but in

occasional shells are irregular in shape. The first 3 or 4 volutions are closely coiled and have a very thin spiral wall scarcely exceeding 20 microns in thickness. The remaining volutions expand gradually and the wall thickens rapidly in the fourth volution and more slowly thereafter, commonly attaining a thickness of 65 to 75 microns in the outer whorl.

Folds are deep and regular on the lower (inner) margin of each septum but die out near the upper margin. Septa are moderately spaced, increasing from 11 or 12 in the first volution to 17 or 18 in the third and 18 to 25 in the fifth. Very slender chomata are present in the first 3 volutions only. The tunnel is moderately wide, and is difficult to measure in good thin sections except in the inner whorls. The tunnel angle measures 30° to 40° in the third volution and increases with acceleration in the outer whorls. A secondary filling is somewhat irregularly distributed along the axial region.

TABLE OF MEASUREMENTS.

whorls	Half length				Radius vector				Form ratio			
	#1	2	3	4	#1	2	3	4	#1	2	3	4
0	.09	.09	.06	.10	.09	.07+	.06	.10	...	...	...	...
1	.30	.22	.14	.23	.14	.12	.09	.16	2.1	1.8	1.6	1.4
2	.50	.36	.31	.50	.18	.18	.14	.20	2.8	2.0	2.2	2.5
3	.95	.60	.56	.80	.28	.26	.24	.29	3.4	2.3	2.3	2.8
4	1.40	.90	.80	1.25	.47	.36	.33	.39	3.0	2.5	2.4	3.2
5	2.40	1.55	1.54	1.95	.66	.49	.46	.50	3.6	3.1	3.3	3.9
6	3.50	2.58	2.64	2.80	.90	.65	.67	.70	3.9	4.0	4.0	4.0
7	4.60	3.90	4.12	4.20	1.16	.90	.87	.95	4.0	4.3	4.7	4.4
8	...	5.05	...	5.50	...	1.10	...	1.20	...	4.6	...	4.6

whorls	Tunnel angle				Wall thickness				Septal count		
	#1	2	3	4	#1	2	3	4	#5	6	7
0	...	...	...	...	.018	.020	.015	.025	...	...	...
1	27°	27°	27°	...	.018	.020	.020	...	12	11	13
2	35°	30°	28°	...	.020	.020	.020	...	16	18	15
3	39°	35°	35°	20°	.022	.020	.020	.030	17	17	18
4	48°	37°	35°	31°	.045	.040	.025	.036	21	20	19
5	...	...	39°	35°	...	.035	.055	.045	24	22	19
6	...	...	42°	41°	...	.050	.050	.060	26	23	...
7	...	...	...	50°	.060	.045	.060	.060	27	...	...
8	...	...	...	...	.075	.045	.065	.060	...	...	...

Specimens 1-6 are illustrated on Plate 2 as Figs. 3, 2, 8, 10, 6, and 5, respectively.

Discussion.—This species most closely resembles *S. prolongada* (Berry) from which it differs in being thicker and evenly fusiform rather than cylindrical, in having a smaller form ratio, and in having rather higher septal folds. Oblique sections of *S. prolongada* appear foreshortened and are easily mistaken for our new species. With a few exceptions these species are not found together in the collections before us, and presumably each has a distinct stratigraphic (or perhaps ecological) distribution.

Distribution.—Found in great abundance in Kozlowski's collections 8 and 16 at Apillapampa, Bolivia. It occurs rarely with *S. prolongada* in Newell's collection 139 near Tiquina.

Schwagerina ahlfeldi Dunbar and Newell, n. sp.

Plate 3, figs. 1-10.

Description.—A small, thickly fusiform species with broadly rounded middle and neatly pointed poles, commonly attaining a length of 5 to 6 mm. and a diameter of 2.5 to 3 mm.; and having 7 to 8 rather closely coiled volutions.

The prolocula commonly range between 150 and 250 microns in diameter and are regularly subspherical. The initial whorls are very tightly coiled and later expansion is slow and gradual; the shape and form ratio of the shell change but little during growth. The spiral wall is very thin in the early whorls and thickens slowly in later volutions, having a thickness of 30 to 45 microns in the third volution and 50 to 70 in the fifth.

As shown in Figs. 5 and 6 of Plate 3, the septa are strongly and regularly folded throughout. The folds extend well up to the outer margin, hence septal loops appear high and narrow and closely spaced in axial sections. Septal pores are present but are commonly not conspicuous because the strong folding causes the septa to cross and recross the slices at high angles. The tunnel is low and narrow, the tunnel angle measuring about 25° to 30° in the third volution, and 25° to 35° in the fifth.

One of the most distinctive features of the species is the heavy secondary deposit which occupies an irregular conical area on each side of the tunnel. It varies considerably in development but in many shells solidly fills the chambers of all the inner whorls except near the tunnel, as shown by an axial section (Fig. 4 of Plate 3) or an excentric section (Fig. 10 of Plate 3).

TABLE OF MEASUREMENTS.

whorls	Half length #1	2	3	Radius vector #1	2	3	Form ratio #1	2	3
0	.10	.116	.10	.10	.116	.10	...	...	...
1	.28	.46	.28	.17	.20	.16	1.6	2.3	1.8
2	.50	.71	.50	.28	.33	.29	1.8	2.1	1.7
3	.65	1.03	.93	.43	.51	.49	1.5	2.0	1.8
4	1.00	1.60	1.30	.57	.73	.73	1.7	2.2	1.8
5	1.20	2.30	1.95	.74	.97	.96	1.6	2.4	2.0
6	1.60	...	2.60	.94	...	1.24	1.7	...	2.1
7	2.00	...	...	1.17	...	...	1.7	...	...
8	3.00	...	...	1.45	...	...	2.0	...	...

whorls	Tunnel angle #1	2	3	Wall thickness #1	2	3	Septal count #4	5
0	...	...	...	.025	.030	.030	...	...
1	...	...	...	.030	.030	.030	13	12
2	21°	25°	35°	.030	.030	.030	22	23
3	24°	30°	...	.035	.043	.030	28	28
4	30°	33°	25°	.043	.050	.043	32	34
5	?	34°	25°	.057	.070	.050	42	38
6	22°	...	23°	.065	...	.057	48	40?
7	20°	...	...	.070	...	...	53	...
8	25°	...	...	...	...	...	...	...

Figures 1-5 are illustrated on Plate 3 as Figs. 4, 1, 2, 7, and 8, respectively.

Discussion.—In shape, septal evolution, and axial filling this species resembles *S. compacta* (White) of the Wolfcamp formation of Texas, but it is distinctly smaller, relatively shorter, and has much larger prolocula.

In size and shape it is extremely like *S. gümbeli* Dunbar and Skinner of the lower Leonard group of Texas, but its whorls are somewhat more closely coiled, especially the early ones, and its axial deposits are more massive and its prolocula generally smaller than in the Texas shells. As shown in a tangential slice of the outer whorls (Fig. 5 of Plate 3), the septal evolution is so far advanced as to foreshadow the development of cuniculi. In this respect also it resembles *S. gümbeli*. Judged by this feature, its age should be late Wolfcamp or possibly early Leonard.

Schwagerina gruperaensis Thompson and Miller, from southernmost Mexico, is also similar to our species, but is much larger, has larger prolocula, and more open coiling.

Distribution.—This species characterizes the upper half of unit 3 of Newell's section on Tiquina Strait. This limestone, about 655 feet thick, extends from about 820 to 1475 feet above the Permian-Devonian contact. Fusulines were collected from six different zones, ranging from near the base to near the top of this limestone. In the upper three, *S. ahlfeldi* occurs in abundance. No other fusulines were found with it in the two upper zones (Collections 145 and 147), but in Collection 143 from a little above the middle of this limestone it is associated with *S.* cf. *S. emaciata* (Beede).

Its absence from the richly fossiliferous beds about Apillapampa and Cochabamba would suggest that unit 3 at San Pedro is a zone not represented in our collections farther south. Nor has it been found in the long section near Muñani or the one near Cerro Pirhuate.

Schwagerina (?) *patens* Dunbar and Newell, n. sp.

Plate 4, figs. 1-8; Plate 8, figs. 11, 12.

Schwagerina aff. *laxissima* Thompson. Jour. Paleont., vol. 17, p. 204, pl. 33.

Description.—An elongate, meloniform species, commonly attaining a length of 11 to 12 mm. and a diameter of 3.2 to 3.5 mm. At this size the shell consists of 6 to 7 very rapidly

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PLATE 1.

Schwagerina prolongada (Berry).

Fig. 1. Holotype, axial section (x 10) from Chulpapampa, Bolivia. This is the specimen illustrated as figure 1 of plate 22 by Berry. It is in the collections of Johns Hopkins University.

Fig. 2. Specimens in the rock (x 1) from Ahlfeld's collection 4 at Apillapampa, Bolivia. Y. P. M. 17382.

Fig. 3. Axial section (x 10) from Ahlfeld's collection 3 at Finca Chacapaya near Sipesple Ceste, Cochabamba Basin, Bolivia. Y. P. M. 17383.

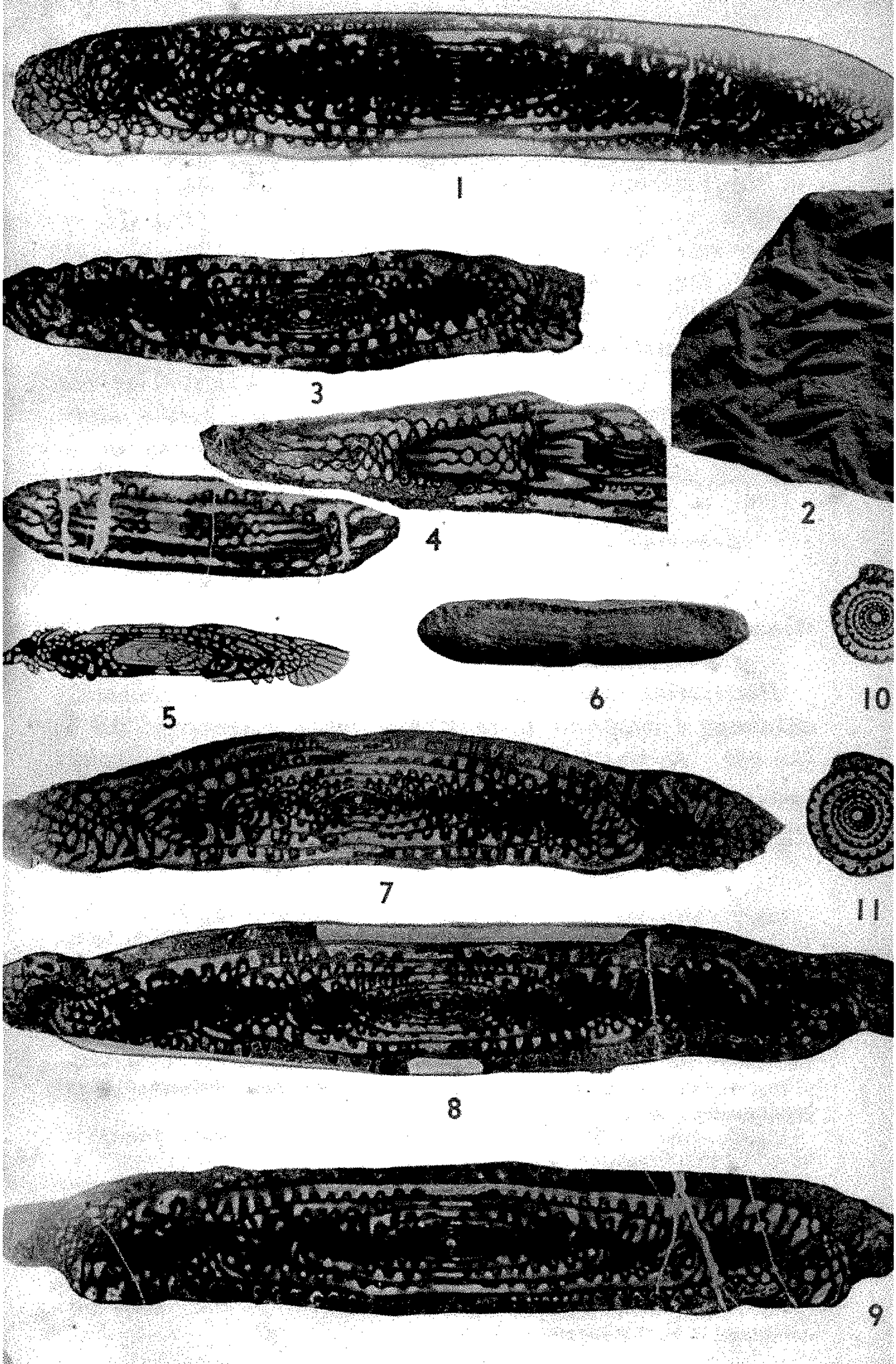
Fig. 4. Tangential slices (x 10) from Koslowski's collection 15 at Apillapampa, Bolivia.

Fig. 5. Copy of Meyer's figure of *Schellwienia convoluta,* reduced to 10/16 of the original.

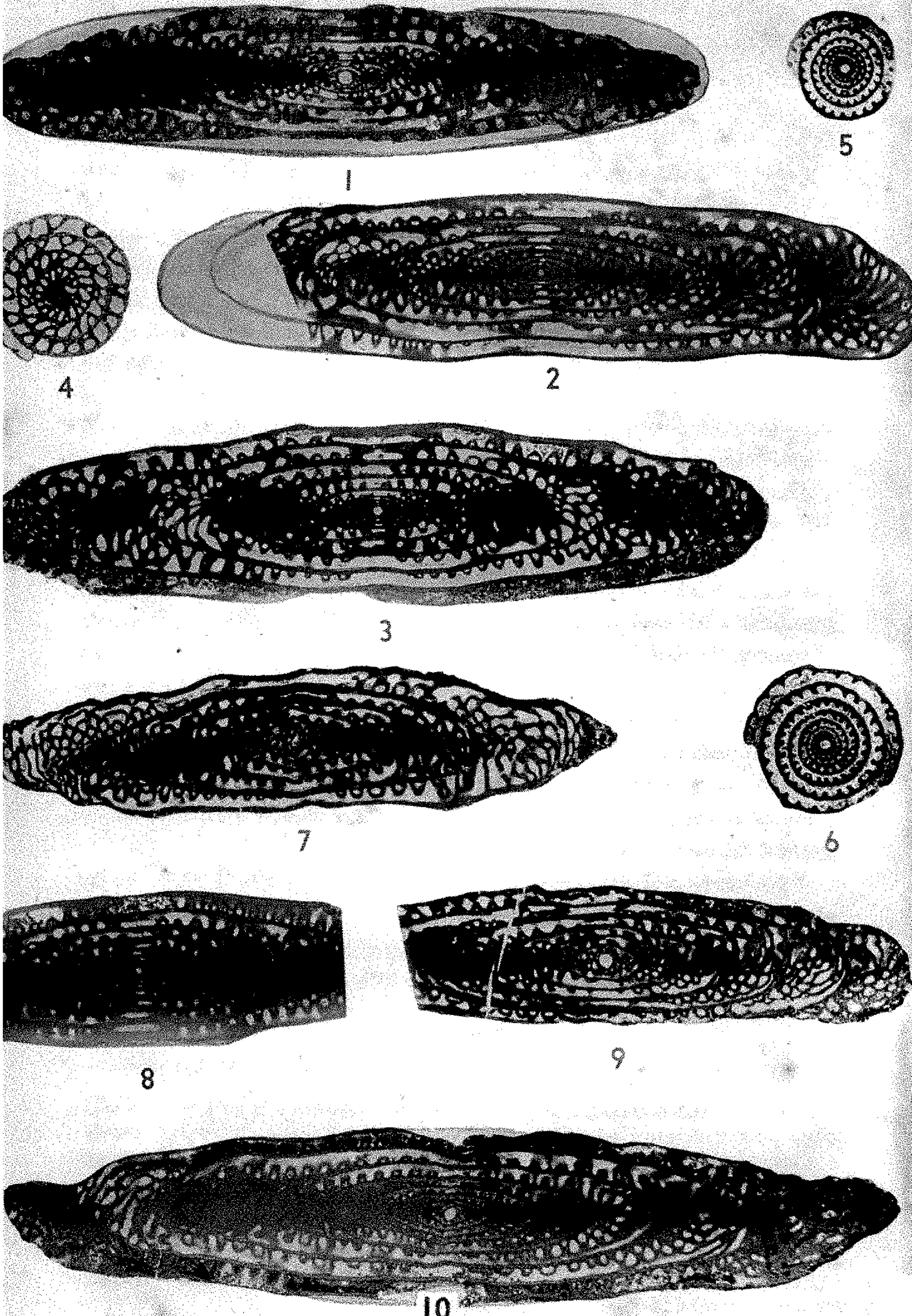
Fig. 6. Paratype immature shell (x 5) from Chulpapampa, Bolivia. This is the specimen represented by figure 11 of Berry's plate 22. It is in the collections of Johns Hopkins University.

Figs. 7, 8. Axial sections (x 10) from Ahlfeld's collection 4 at Apillapampa, Bolivia. Y. P. M. 17384, 17385.

Figs. 9-11. Axial and two sagittal sections (x 10) from Koslowski's collection 15 at Apillapampa, Bolivia.



Schwagerina prolongada
(Berry)



Schwagerina steinmanni

expanding volutions. The ends of the shell are commonly unsymmetrical and the axis not straight.

The prolocula show a range in size from less than 200 to nearly 400 microns in diameter but commonly measure between 250 and 300 microns.

The ontogeny of this shell is distinctive. The innermost whorls are short and thick and rather tightly coiled, and have a relatively thick wall and well developed chomata and considerable epithecal deposit. But the rate of expansion is exceptionally high and the outer volutions appear high and loosely coiled. Chomata disappear in the third or fourth volution; the wall increases slowly in thickness in the outer whorls. The net result is that the early whorls appear as a thick-walled and closely coiled nucleus in the middle of a large, loosely coiled shell. In either axial or sagittal section they appear at first glance to have the characters of an elongate *Pseudoschwagerina*. But critical examination of the sagittal sections shows that the dense central nucleus owes its appearance largely to the thick chomata and other epithecal deposit—the radial expansion is gradual although somewhat irregular. The septa are rather strongly folded but in the high outer volutions the folds are large and in axial sections the loops appear rounded and very irregular. Septal pores are abundant but unusually small.

The tunnel is low and uncommonly variable in width. In the first 3 or 4 volutions it is clearly defined by the bordering chomata, but in the outer whorls it is difficult to observe in good thin sections.

Specimens 2-7 are illustrated on Plate 4 as Figs. 1, 7, 8, 6, 4, and 5, respectively.

Discussion.—This species is very similar to *Schwagerina* (?) *laxissima* Dunbar and Skinner of the Wolfcamp series in Texas,

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PLATE 2.

Schwagerina steinmanni Dunbar and Newell, n. sp.

Fig. 1. Axial section (x 10) from Ahlfeld's collection 8 at Finca Chacapaya near Sipesple Ceste of Cochabamba Basin, Bolivia. Y. P. M. 17386.

Figs. 2, 3, 8. Axial sections (x 10) from Kozlowski's collection 16 at Apillapampa, Bolivia. Figure 8 shows the holotype.

Figs. 4-6. Excentric and two sagittal sections (x 10) from same locality.

Figs. 7, 9. Axial sections (x 10) from Newell's collection 189 near Tiquina Strait. Y. P. M. 17426, 17427.

Fig. 10. Axial section (x 10) from bed 3 of Newell's section at Tiquina. Newell collection 146. Y. P. M. 17428.

TABLE OF MEASUREMENTS.

whorls	Half length #1	2	3	4	Radius vector #1	2	3	4	Form ratio #1	2	3	4
0	.13	.14	.21	.10	.12	.14	.18	.10	1.0	1.0	1.1	1.0
1	.31	.30	.47	.24	.16	.23	.33	.17	1.3	1.3	1.4	1.4
2	.70	.74	.93	.47	.33	.33	.49	.30	2.1	2.2	1.8	1.5
3	1.57	1.33	2.28	1.20	.61	.47	.74	.47	2.5	2.8	3.0	2.5
4	3.29	2.28	3.00	2.20	.94	.70	1.17	.61	3.5	3.2	2.5	3.3
5	...	3.00	3.57	4.10	...	1.16	1.71	1.03	...	2.5	2.0	4.0
6	...	4.00	...	5.60	...	1.48	...	1.45	...	2.7	...	3.8

whorls	Tunnel angle #1	2	3	4	Wall thickness #1	2	3	4	Septal count #5	6	7
0	...	...	...	...	.025	.035	.035	.020	...	...	...
1	20°	20°	22°	16°	.022	.030	.045	.020	15	18	15
2	31°	20°	40°	20°	.033	.040	.035	.035	25	28	32
3	42°	33°	55°	24°	.050	.050	.050	.045	32	35	30
4	...	...	...	24°	.045	.075	.055	.040	32	30	32
5	...	...	...	...	...	.070	.075	.050	36	...	35
6	...	...	...	...	...	.080	...	.090	...	...	...

of which it may prove to be only a geographical subspecies. The South American form has a thinner wall and tends to develop chomata in one more volution than the Texas form.

The correct generic assignment of both these species is problematical. Obviously they are descended from *Triticites*, and during their youth could not be distinguished from that genus. But their adult volutions have the characters of *Schwagerina* in that their septa are strongly folded and chomata are obsolete. In their high outer volutions they mimic *Pseudoschwagerina* and strikingly resemble species such as *P. d'orbignyi* and *P. texana*. But they fail to show the sudden inflation at the end of the juvenile stage which is characteristic of *Pseudoschwagerina*, and their walls are notably thicker than is normal for that genus.

The specimen illustrated in Figs. 11 and 12 on Plate 8 shows a unique and puzzling biologic feature. Near one end of the penultimate volution the shell has incorporated the shell of a juvenile individual of the same species. The young shell consisted of a proloculum and approximately one volution. Well defined chomata adhering to the surface of the proloculum define the tunnel and clearly indicate the orientation of the young shell which is approximately at right angles to that of the large one.

There is no possibility that this small shell was introduced as a foreign object after the large shell was empty. Preservation is exceptionally perfect and no matrix had entered the large shell. Moreover, it is evident that the small shell is enveloped in a tangle of septal folds and was actually overgrown by the large one.

Occasional shells of many species of fusulines are found with a double proloculum which appears to indicate that two young individuals had fused completely; but in such cases the individuals were at almost identically the same growth stage when fusion occurred, and it appears possible that it may represent some kind of sex phenomenon akin to the conjugation that is common among the Ciliophora. But the fusion of a very young with a nearly mature individual is an enigma. Is it possible that the adult devoured a young individual and then, instead of rejecting the shell of the latter, grew around and invested it?

Distribution.—This species occurs in abundance in Kozlowski's collection 1 and in Newell's collection 188 at Yaurichambi, Bolivia. In the latter it is associated with rare specimens of *Triticites boliviensis*, n. sp.

This is the species which Thompson (1943, p. 204) described as *Schwagerina* aff. *laxissima* Dunbar and Skinner from a deep well in the Agua Caliente oil field in the Department of Loreto northeast of Tarma.

Schwagerina muñaniensis Dunbar and Newell, n. sp.

Plate 11, figs. 7-13.

Description.—A small, thickly fusiform species with inflated middle and neatly pointed poles, commonly attaining a length of 5 to 6 mm. and a diameter of 2.5 to 2.6 mm. Shells of this size have about 6 volutions.

The prolocula are small, thin walled, and spheroidal. The first whorl is closely coiled about the small proloculum but the expansion is rapid and the outer volutions are relatively high. The spiral wall is thin, having a thickness of 25 to 30 microns in the second whorl and rarely exceeding 70 microns in the outer whorls.

The septa are strongly folded throughout. The tunnel is narrow but is difficult to measure in thin sections because of the

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septal folding and the lack of chomata. In the first 2 or 3 whorls there are very low, slender chomata but they are obsolete in the remaining volutions.

TABLE OF MEASUREMENTS.

Whorls	Half length #1	2	3	4	Radius vector #1	2	3	4	Form ratio #1	2	3	4
0	.045	...	.09	.096	.045	.086	.08	.096	...	...	...	...
1	.14	...	.30	.30	.12	.14	.12	.16	1.2	2.5	2.5	1.9
2	.30	.40	.60	.60	.17	.23	.21	.23	1.8	2.0	2.9	2.6
3	.60	.80	1.00	.90	.30	.36	.40	.36	2.0	2.0	2.5	2.5
4	1.20	1.40	1.70	1.30	.51	.60	.70	.67	2.3	2.0	2.4	2.0
5	1.90	2.10	2.60	2.20	.93	1.00	1.16	1.00	2.0	1.9	2.2	2.2
6	2.60	2.85	...	3.20	1.43	1.40	...	1.36	1.8	2.0	...	2.3

Whorls	Tunnel angle #1	2	3	4	Wall thickness #1	2	3	4
2	...	25°	20°	26°	.025	.029	.029	.029
3	19°	35°	29°	26°	.030	.030	.036	.043
4	27°	43°	29°	33°	.050	.060	.050	.070
5	...	34°	27°	31°	.070	.070	.080	.070
6	...	...	...	28°	...	.070	...	.070

Specimens 1-4 are illustrated on Plate 11 as Figs. 8, 9, 10, and 13, respectively.

Discussion.—In its thin wall, loose coiling and strong septal folding, this species resembles *S. nelsoni* Dunbar and Skinner of the Wolfcamp series in Texas, but is only about half as large in corresponding volutions and scarcely attains half the size of the Texas shell. Also it has a much smaller proloculum.

In size and proportions, it resembles *S. bellula* of the Wolfcamp series in Texas. That species also has very small prolocula and high, strong septal folds, but its wall is thicker and it tends to develop epithecal filling along the axis.

Distribution.—This species is fairly common in Newell's collection 92 from the Cretaceous conglomerate that rests on the Permian section near Muñani, Peru. The specimen shown as Fig. 7 on Plate 11 was found in Kozlowski's collection 2 at Yaurichambi, where it is associated with *Pseudoschwagerina kozlowskii.*

Schwagerina sp. A

Plate 8, fig. 11.

Associated with *Schwagerina ahlfeldi* in collection N145 from the Tiquina section is an axial section of a shell that resembles that species in general shape and size and in the intensity of its high septal folds. But this shell has a large proloculum (260 microns in diameter) and its inner whorls are few and loosely coiled. Moreover, it has almost no axial filling.

This shell is well outside the range of variation shown by a large number of sections of *S. ahlfeldi*, but whether it represents an individual aberration or a variety or a distinct species cannot be determined until more shells of this type are found.

Schwagerina cf. *S. emaciata* (Beede)

Plate 8, figs. 12, 13.

In Kozlowski's collection from Yaurichambi we find two axial sections of a small slender *Schwagerina* distinctly different from any other species seen in our Andean collections but remarkably similar to *S. emaciata* of the Wolfcamp series in the United States.

One consists of 6½ volutions and has a length of 4.6 mm. and a diameter of 1.6 mm.; the other includes 7½ volutions and has a length (restored) of about 5.7 mm. and a diameter of 1.85 mm. The prolocula are very small, that of the first specimen having a diameter of 100 microns and that of the second only 95 microns. The wall reaches a maximum thickness of about 70 microns in the outer whorl and is rather coarsely alveolar. The septal folds are strong and septal loops high and narrow. A trace of slender chomata can be seen in the first 2 or 3 volutions. The tunnel angle is narrow, rising to about 30° in the fifth and sixth whorls.

Comparison with the illustrations and measurements of *S. emaciata* (Beede) as given by Dunbar and Skinner in 1937 (p. 633 and pl. 56) will show that all the data cited above fall within the limits of the Beede species. Direct comparison of superposed thin sections confirms the identity and we only hesitate to apply the name of the Wolfcamp species to the South American form without additional sections.

Occurrence.—Two specimens, only, were found in Kozlowski's collection 7 at Yaurichambi where they are associated with *Pseudoschwagerina d'orbignyi, Triticites patulus, T. titicaca-*

ensis, and *T. opimus*. Several specimens apparently belonging to this species were found also in Newell's collection 92-C in bed 3 of the section near Muñani where it has approximately the same associations.

Pseudoschwagerina koslowskii Dunbar and Newell, n. sp.
Plate 5, figs. 1-7.

Description.—A thickly fusiform species with evenly elliptical axial profile and subacutely pointed poles. It commonly has about 5 volutions and attains a length of 8 to 9 mm. and a diameter of 4 to 5 mm., the form ratio varying from 1.7 to 2.2.

The proloculum shows a considerable range in size, being only 140 microns in diameter in measured specimen no. 5 but 230 microns in specimen no. 6 and 400 microns in another specimen, but it is commonly between 175 and 250 microns in diameter and is subspherical.

The juvenarium commonly includes about 2½ volutions but if the proloculum is small it may amount to 3½ volutions and if the proloculum is large the juvenarium may be reduced to 2 volutions. In this portion of the shell the whorls are low and the tunnel is bordered by rather slender but well defined chomata. Following the juvenarium the whorl rapidly increases in height, commonly reaching a maximum within half a volution and then declining again in the last whorl as well shown in Figs. 6 and 7 of Plate 5. Chomata are usually completely lacking in the inflated whorls.

The spiral wall is alveolar, showing well defined tectum and keriotheca and increasing gradually in thickness from 20 to 30 microns in the first whorl to about 50 microns in the third and commonly near 100 microns in the fifth.

The septa are gently folded but since they are widely spaced in the inflated whorls the septal loops appear sparse and extremely irregular in axial sections. The true extent of folding is better shown in the juvenile whorls where the septa are more closely spaced and invariably lie near the plane of the section. As shown in Fig. 7 of Plate 5, the septa appear short and thick in the juvenile whorls and very long and much thinner in the inflated whorls. Septal pores are abundant in the inflated whorls.

The tunnel is rather narrow in the juvenile whorls where it is bounded by narrow chomata; but in the inflated whorls it can

seldom be measured in thin sections because the septa are so spaced that only rarely does one coincide with the slice. Commonly the septal folds increase in depth in the outer volution.

Statistical measurements tabulated below show large discrepancies between individual shells as is common in this genus. This springs partly from the large variation in the size of the prolocula and the fact that the number of volutions in the juvenarium varies inversely with its size. Thus, for example, the third volution of specimen no. 1 is in the inflated part and in specimen no. 2 it is in the juvenarium. Furthermore, in shells that expand so rapidly, apparent discrepancies are notable if the slices do not fall precisely in the plane coincident with the ends of complete volutions. That is, if one shell is measured exactly at the ends of volutions 1, 2, 3, and 4, and another at ¾, 1¾, 2¾ and 3¾ volutions, the former will appear to be considerably larger even though the shells are equal in size and shape.

TABLE OF MEASUREMENTS.

whorls	Half length				Radius vector				Form ratio			
	#1	2	3	4	#1	2	3	4	#1	2	3	4
0	.12	.09	.12	.14	.12	.09	.12	.14	1.0	1.0	1.0	1.0
1	.45	.27	.43	.46	.25	.20	.20	.29	1.8	1.4	2.1	1.5
2	.90	.60	.90	1.10	.50	.34	.40	.51	1.8	1.8	2.2	2.1
3	1.80	.90	1.80	2.17	1.10	.50	.80	1.20	1.7	1.8	2.2	1.8
4	3.10	2.20	3.00	3.30	1.85	1.00	1.60	1.95	1.7	2.2	1.9	1.7
5	4.40	3.40	...	...	2.25	1.70	2.10	...	1.9	2.0	...	...

whorls	Tunnel angle				Wall thickness				Septal count		
	#1	2	3	4	#1	2	3	4	#5	6	7
0	...	...	...	...	.020	...	.020	...	...	...	...
1	35°	32°	28°	27°	.027	.020	.030	.030	10	11	10
2	38°	34°	34°	37°	.034	.030	.050	.050	13	17	18
3	?	36°	22°	20°	.050	.050	.050	.060	17	15?	17
4	33°	?	...	...	.060	.060	.070	.080	20	26?	?
5	...	...	...	...	.090	.070	.110	...	16	...	...
6	...	...	...	...	...	...	...	...	25?	...	...

Specimens 1, 2, 3, and 5 are illustrated as Figs. 4, 2, 3, and 7, respectively, on Plate 5.

Discussion.—This species is intermediate in shape between *P. uddeni* and *P. texana* of the United States. It is less inflated than the former and its volutions never attain as great height;

and it is not so slender and elongate as *P. texana* and its septa are less strongly folded. It is very similar in size and shape to *P. beedei* Dunbar and Skinner from the basal Wolfcamp in the Hueco Mountains, but it appears to be constantly somewhat more slender in the juvenile whorls.

Occurrence.—This is a common species in Kozlowski's collections, being present in collection 5 from Yaurichambi, in collections 9, 11, 12, 13, 14, and 18 from Apillapampa, and in collections 19, 20, and 21 from Carpacayma. It is abundant in Newell's collection 92C from unit 3 of his section near Muñani, Peru, which is about 1000 feet above the base of the Permian at that locality. It is also common in Newell's lot 92 which was collected from boulders in the base of the Cretaceous where it rests upon the Permian.

At several localities it is associated with *Pseudoschwagerina d'orbignyi* and with *Schwagerina prolongada* and *Triticites boliviensis*.

Pseudoschwagerina d'orbignyi Dunbar and Newell, n. sp.

Plate 6, figs. 1-9.

Description.—A slender species for this genus with bluntly rounded poles and without an equatorial bulge, the axial profile

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PLATE 8.

Schwagerina ahlfeldi Dunbar and Newell, n. sp.

Figs. 1, 2. Paratype axial sections (x 10) from near the top of unit 3 of Newell's section at San Pedro, Strait of Tiquina, Copacabana Peninsula, Bolivia. Newell's collection 145. Y. P. M. 17429.

Figs. 3, 4. Paratype and holotype axial sections (x 10) from a loose block on the outcrop at the same locality. Newell's collection 140. Y. P. M. 17431, 17432.

Figs. 5, 6. Slightly tangential section and tangential slice (x 10) from same rock specimen as the last. Newell's collection 140. Y. P. M. 17433, 17432.

Figs. 7, 8. Paratype sagittal sections (x 10) from same locality as the last. Newell's collection 140. Y. P. M. 17434, 17435.

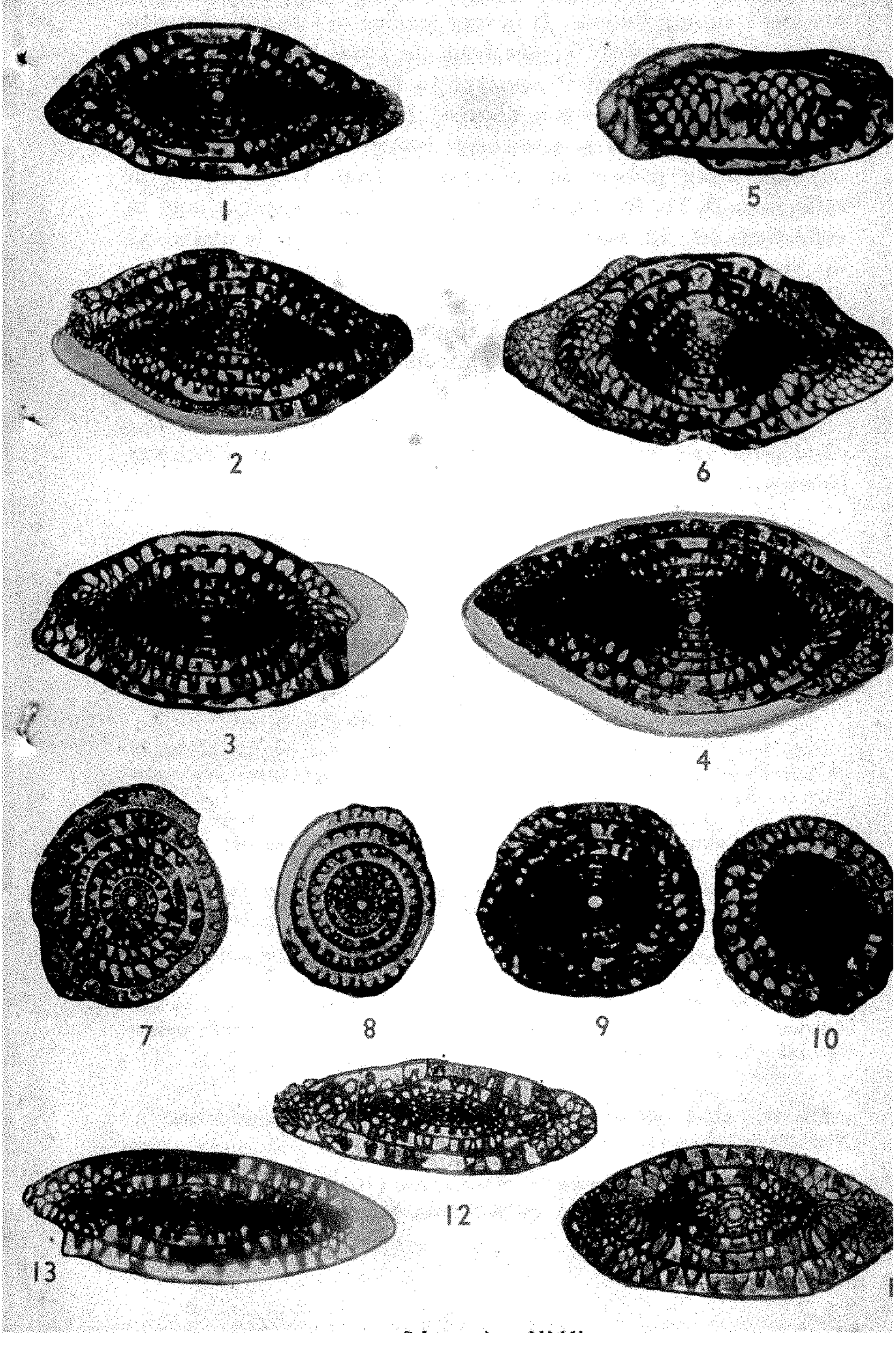
Figs. 9, 10. Slightly oblique sagittal section and excentric section (x 10) showing the heavy axial filling. Same locality as the last. Newell's collection 145. Y. P. M. 17436.

Schwagerina sp. A.

Fig. 11. Axial section (x 10) from same bed as figures 1 and 2. Newell's collection 145. Y P. M. 17437.

Schwagerina cf. *S. emaciata* (Beede)

Figs. 12, 13. Axial sections (x 10) from Kozlowski's collection 7 at Yaurichambi.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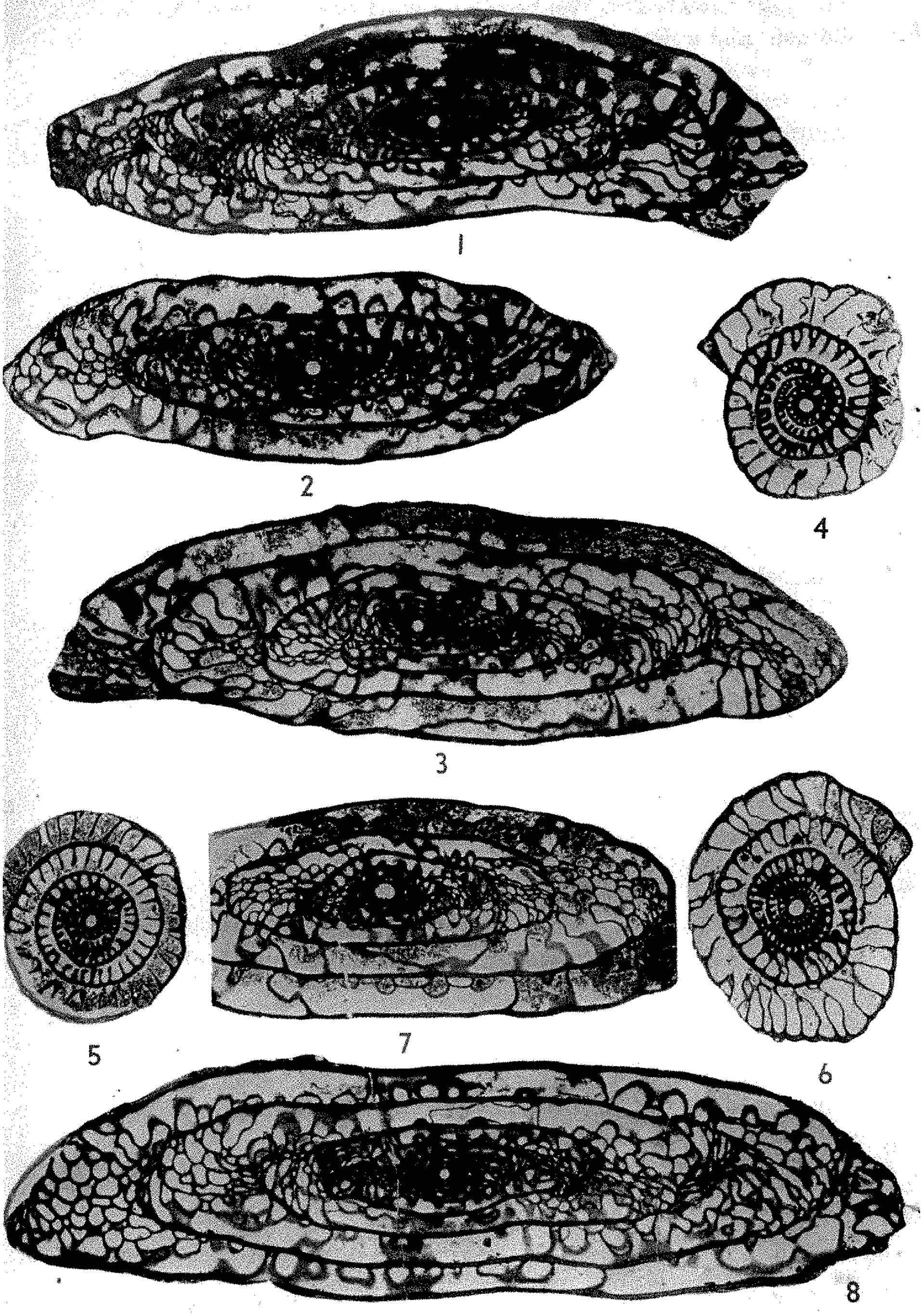

Schwagerina patens

being an elongate ellipse with a form ratio commonly about 2.5. The shell has about 5 volutions and reaches a length of 5.5 to 6.5 mm. and a diameter of 2.0 to 3.0 mm.

The prolocula range from less than 150 to about 340 microns in diameter and the juvenarium includes from 1½ to 3½ volutions, the number varying inversely with the size of the proloculum. Accordingly, the statistical measurements as tabulated below appear rather widely discordant since the second or third volution in one shell may represent the tightly coiled juvenarium and in another the inflated part of the shell. For example, specimen no. 1 with a smaller proloculum and 5 volutions corresponds very closely in adult size and shape with specimen no. 4 which has a larger proloculum and only 4 volutions.

In the juvenarium there are well defined but slender chomata that disappear in the first of the inflated whorls. The inflation is not quite so rapid as in *P. kozlowskii*, the whorls do not reach so great a height, and the poles are more bluntly rounded.

The spiral wall is like that of *P. kozlowskii* in structure and thickness.

The septa are widely spaced, as is usual in this genus, and are gently folded so that in axial sections the septal loops appear sparse and very irregular. There is a tendency for the lower margin of the septa to be more deeply folded in the outer whorl. The final volution commonly decreases in height, as shown in Figs. 8 and 9 of Plate 6, and the septa are more closely spaced. In some shells these last chambers show a rather close tangle of septal loops. Septal pores are abundant in the inflated whorls.

The tunnel is rather wide, increasing from 20° or 30° in the first volution to 50° or 60° in the fourth. It is clearly defined by the chomata in the juvenile whorls but is commonly not well

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PLATE 4.

Schwagerina (?) *Patens* Dunbar and Newell, n. sp.

Figs. 1, 4, 6. Paratype axial section and two sagittal sections (x 10), from Kozlowski's collection 1 at Yaurichambi.

Figs. 2, 3, 5. Paratype axial sections and a sagittal section (x 10) from Newell's collection 138 at Yaurichambi, Bolivia. Y. P. M. 17438-17440.

Fig. 7. Axial section (x 10) from Kozlowski's collection 1 at Yaurichambi.

Fig. 8. Holotype axial section from Newell's collection 138 at Yaurichambi, Bolivia. Y. P. M. 17441.

shown in good thin sections of the outer whorls where it can be studied best in thick sections or polished surfaces.

Specimens 1, 2, 3, 4, 5, and 6 are illustrated as Figs. 2, 4, 5, 6, 8, and 9, respectively, of Plate 6.

Discussion.—This species is distinguished from *P. kozlowskii* by its shape and form ratio. Its proportions resemble those of

TABLE OF MEASUREMENTS.

whorls	Half length				Radius vector				Form ratio			
	#1	2	3	4	#1	2	3	4	#1	2	3	4
0	.09	.17	.08	.10	.09	.14	.08	.10	1.0	...	1.0	1.0
1	.35	.70	.50	.60	.16	.35	.12	.19	2.2	2.0	4.0	3.0
2	.70	1.50	1.10	1.50	.28	.65	.40	.32	2.5	2.3	2.7	4.7
3	1.50	2.40	2.10	2.75	.50	1.20	.90	.50	3.0	2.0	2.3	5.5
4	2.70	4.10	3.90	4.20	1.00	1.60	1.55	1.20	2.7	2.6	2.5	3.5
5	...	...	4.90	...	...	...	1.80	1.60	...	...	2.7	...

whorls	Tunnel angle				Wall thickness				Septal count		
	#1	2	3	4	#1	2	3	4	#5	6	7
0	...	...	...	...	.020	.030	.015	.030	...	...	...
1	20°	28°	?	30°	.015	?	.015	?	10	9	10
2	31°	38°	39°	35°	.020	.050	.020	.030	15	16	14
3	37°	36°	39°	43°	.040	.085	.050	.045	18	16	16
4	61°	?	50°	50°	.060	.085	.070	.065	23	18	17
5	...	...	...	...	.090	?	.085	?	23	18	?
6	...	...	...	...	...	...	...	...	30	28	?

P. texana of the United States but its ends are thicker and more bluntly rounded and its axial profile elliptical rather than fusiform. It is also considerably smaller than *P. texana.*

PLATE 5.

Pseudoschwagerina kozlowskii Dunbar and Newell, n. sp.

Fig. 1. Specimens in the stone (x 1) from Kozlowski's collection 20 at Carpacayma, Bolivia. The more slender specimens belong to the species *P. d'orbignyi,* n. sp.

Fig. 2. Paratype axial section (x 10) from Kozlowski's collection 9 at Apillapampa, Bolivia.

Fig. 3. Paratype axial section (x 10) from Kozlowski's collection 18 at Apillapampa.

Fig. 4. Holotype axial section (x 10) from Kozlowski's collection 11 at Apillapampa.

Fig. 5. Paratype axial section (x 10) from Newell's collection 92 at the top of the Permian section near Muñani, Peru. Y. P. M. 17442.

Figs. 6, 7. Paratype sagittal sections (x 10) from Kozlowski's collection 9 at Apillapampa.

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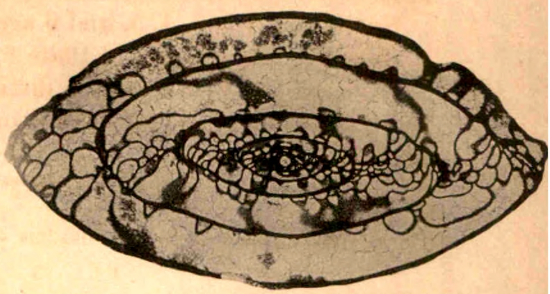

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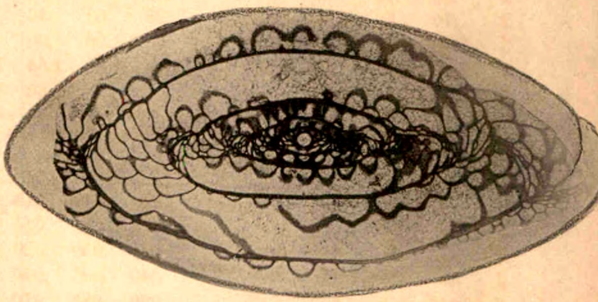

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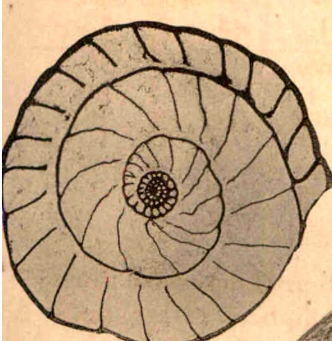

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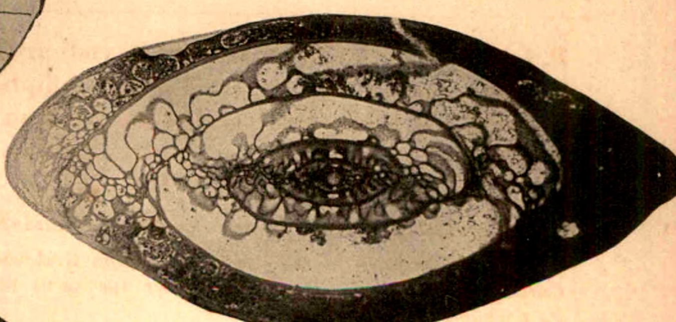

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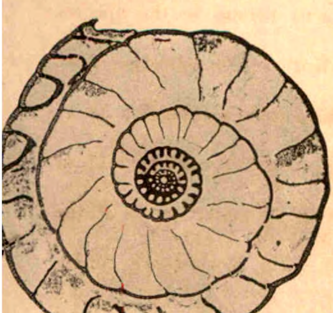

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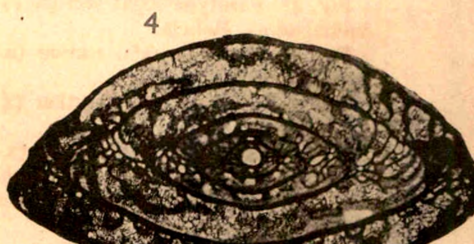

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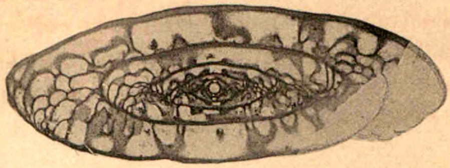
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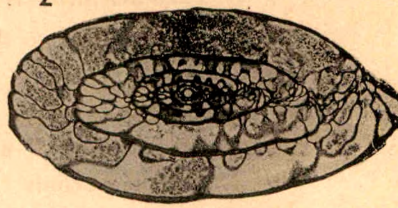
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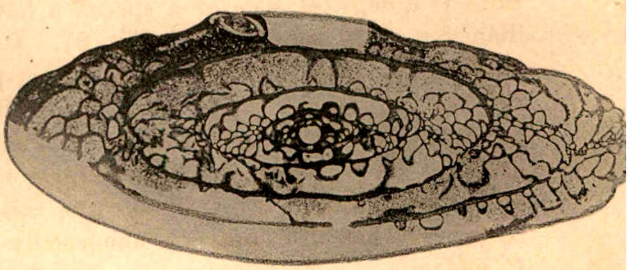
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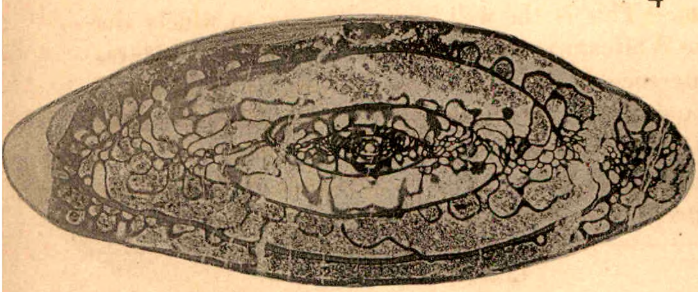
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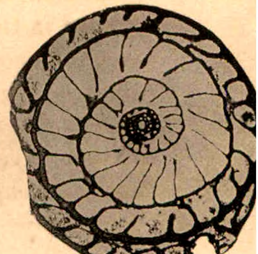
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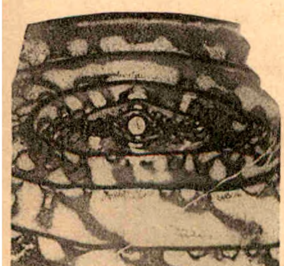
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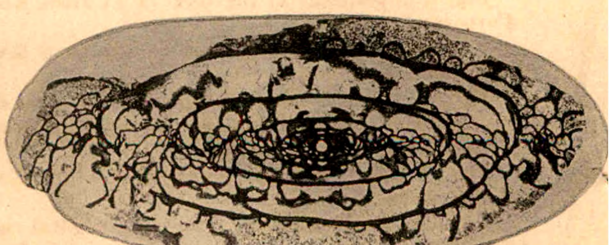
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Pseudoschwagerina d'orbignyi

Occurrence.—This species has been found in Kozlowski's collection 5 at Yaurichambi; in collections 11, 14, and 18 at Apillapampa; and in collection 19 at Carpacayma. In each of these it is associated with *P. kozlowskii* and in the last two lots with *Schwagerina prolongada.*

Pseudoschwagerina uddeni (Beede and Kniker)

Plate 7, figs. 1-5; Plate 12, fig. 8.

Discussion.—It was a matter of great surprise to find this well known Texan species in South America, and we were predisposed to describe it as new; but after careful comparison with numerous sections from Texas we are unable to find any characters that would justify a distinction. Among our sections is a sagittal slice of a specimen having the remarkable diameter of 10 mm. (Pl. 12, Fig. 8). Its penultimate whorl reaches a height of .22 mm. This is the specimen to which we referred in a preliminary note (Amer. Jour. Sci., vol. 243, p. 218) as "the largest species of *Pseudoschwagerina* yet known." It is, apparently, the largest specimen yet known, but after cutting many sections from this lot we are inclined to believe that it is only an abnormally large individual of *P. uddeni.*

Distribution.—This is the well known species so widely distributed in the Wolfcamp strata of southwestern United States. Its only occurrence in the collections before us from South America is in unit 7 of Newell's section at Cerro Pirhuate, Peru, where it is extremely abundant. In the same unit, but not in the same layer, we find *Schwagerina prolongada, S.* (?) *patens, Pseudoschwagerina kozlowskii,* and *Triticites patulus.*

PLATE 6.

Pseudoschwagerina d'orbignyi Dunbar and Newell, n. sp.

Fig. 1. Specimens in the rock (x 1) from Kozlowski's collection 19 at Carpacayma, Bolivia.

Fig. 2. Juvenile axial section (x 10) from Kozlowski's collection 18 at Apillapampa, Bolivia.

Figs. 3, 5, 6, 9. Two paratypes, the holotype axial section, and a paratype sagittal section (x 10) from Kozlowski's collection 11 at Apillapampa. Figure 6 shows the holotype.

Fig. 4. Paratype axial section (x 10) from Kozlowski's collection 14 at Apillapampa.

Figs. 7, 8. Incomplete axial and sagittal section from Kozlowski's collection 19 at Carpacayma.

Triticites berryi (Willard Berry)

Plate 8, figs. 1-10.

Schellwienia berryi Jones mss.

Fusulina berryi Berry. Pan-American Geologist, vol. 59, 1933, p. 270, pl. 22, figs. 6 and 7 [not 10].

Description.—A small species of 7 to 8 volutions attaining a length of 7.0 to 8.0 mm. and a diameter of 2.0 to 2.5 mm. The shape is evenly fusiform with gently convex lateral slopes tapering to rounded poles.

The prolocula commonly range between 120 and 150 microns in diameter. The early whorls are relatively short and the form ratio increases steadily with growth from about 2.0 in the second whorl to 3.5 or 4.0 at maturity.

The wall is of moderate thickness, increasing gradually from about 40 microns in the third whorl to a maximum of 65 to 80 microns in the sixth. It has the typical structure for *Triticites*, the keriotheca being well developed.

The septa are rather widely spaced for a shell of such small size and the number increases but slowly in successive whorls, scarcely exceeding 20 in the outer volution. However, they are rather strongly folded for this genus. Septal pores are

TABLE OF MEASUREMENTS.

whorls	Half length #1	2	3	4	Radius vector #1	2	3	4	Form ratio #1	2	3	4
0	.07	.07	.06	.06	.07	.057	.06	.06	...	...	...	...
1	.23	.20	.23	.17	.14	.10	.12	.10	1.6	2.0	2.0	1.7
2	.37	.44	.40	.33	.21	.16	.20	.16	1.8	2.8	2.0	2.0
3	.74	.61	.71	.61	.33	.26	.29	.24	2.2	2.3	2.4	2.5
4	1.33	.94	1.23	1.06	.50	.36	.43	.36	2.6+	2.6	3.0	2.9
5	2.14	1.45	2.03	1.55	.73	.53	.64	.56	3.0	2.7	3.0	2.8
6	3.46	2.45	2.86	2.45	1.01	.74	.89	.71	3.4	3.3	3.1	3.4
7	4.30+	...	...	3.76	1.21	.91	1.14	.97	3.5+	...	...	4.0

whorls	Tunnel angle #1	2	3	4	Wall thickness #1	2	3	4	Septal count #5	6
1	...	...	...	...	...	...	...	...	12	13
2	...	20°	28°	...	...	...	...	...	17	15
3	27°	27°	33°	31°	...	.040	...	...	17	16
4	28°	26°	36°	41°	...	.043	...	.045	14	18
5	40°	39°	41°	40°	.065	.050	...	.065	19	19
6	45°	39°	57°	49°	.070	.078	...	...	18	21
7	49°	50°	...	56°	...	...	...	.065	19	...

plentiful in the outer whorls, especially in the end zones. Chomata are well developed but not massive. The tunnel tends to widen progressively, its angle being near 30° in the third volution and near 50° in the seventh.

Specimen 1 is the holotype. Specimen 1, 2, 5, and 6 are illustrated on Plate 8, as Figs. 7, 4, 10, and 9, respectively.

Discussion.—The original illustrations included 3 figures, an axial and a sagittal section, and an external view of a specimen with one end missing. The latter shows the antetheca which is very regularly and strongly folded, even across the middle of the shell. We are convinced, however, that this unsectioned specimen belongs to a different species, *Schwagerina prolongada.* Accordingly, the axial section figured by Doctor Berry (our Plate 6, Fig. 7) is here designated the holotype of the species. Fortunately, the original lot from which the types were selected includes abundant specimens and of these we have cut 9 axial and 3 sagittal sections. These agree closely and are undoubtedly conspecific with the holotype section. But associated with them is another specimen which externally agrees closely with the one used by Berry to illustrate the exterior of this species (his plate 22, figure 10). Berry's original has been kept intact but its mate was photographed and then cut down to the axis. It was then discovered to have a well marked axial filling and all the other characters of *Schwagerina prolongada.* There can be little doubt that the specimen shown by Berry's plate 22, figure 10, has the same characters. In the original lot studied by Doctor Berry there are, however, several specimens showing the characteristic shape of *T. berryi* which he had cut down to the axial plane and which can be definitely identified with the thin sections. We have introduced figures of these (Plate 8, Figs. 4, 5, 6, 9, 10).

The holotype axial section is much thicker than the usual thin sections and for this reason the septa appear denser and the septal loops more abundant than they do in the other thin sections, but, if cut thinner, part of these would disappear.

Occurrence.—The types are from Chulpapampa, Bolivia, but the species was identified by Berry from Yampupata, also. The types are preserved at Johns Hopkins University.

The species occurs in Kozlowski's collection 6 from Yaurichambi, and in his collection 10, 11, and 16 from Apillapampa, Bolivia.

Triticites patulus Dunbar and Newell, n. sp.

Plate 10, figs. 1-10.

Fusulina peruana Willard Berry [non Meyer]. Pan-American Geologist, vol. 59, 1933, p. 269, pl. 22, figs. 4, 8, 9, 12.

Description.—Shell thickly fusiform (or elliptical in axial profile) with bluntly rounded poles; attaining a length of 5 to 6 mm. and a diameter of 2.5 to 3.0 mm., and at this size consisting of 6 to 7 volutions. The majority of the shells seen are somewhat smaller and are probably immature, having 5 to 6 volutions.

The prolocula range between 125 and 250 microns in diameter with the mean around 200 microns. The inner volutions are rather closely coiled, but the expansion is rapidly accelerated so that the outer volutions are exceptionally high. This is a distinctive feature of the species and gives the shell considerable resemblance to *Pseudoschwagerina* from which, however, it is distinguished by its gradual inflation, its heavier chomata and its thicker wall.

The spiral wall is rather thick, ranging from 25 to 30 microns in the first volution up to 90 microns in the sixth. It is distinctly alveolar with a well differentiated tectum and keriotheca. The tunnel is high and narrow and the chomata are rather massive in the first 3 or 4 volutions but become obsolete in the highly inflated outer whorls.

The septa are rather strongly folded for this genus. Septal pores are abundant but rather small, and are easily overlooked as a result of the strong folding which causes the septa to cross thin sections at a high angle.

TABLE OF MEASUREMENTS.

whorls	Half length				Radius vector				Form ratio			
	#1	2	3	4	#1	2	3	4	#1	2	3	4
0	.065	.085	.086	.057	.065	.085	.086	.057	...	...	...	...
1	.15	.25	.20	.12	.12	.15	.14	.10	1.2	1.7	1.4	1.2
2	.30	.50	.57	.21	.21	.26	.24	.18	1.4	1.9	2.3	1.1
3	.60	1.00	1.00	.46	.35	.43	.41	.30	1.7	2.3	2.4	1.5
4	1.15	1.55	1.70	.87	.57	.64	.64	.49	2.0	2.4	2.0	1.7
5	1.55	2.50	2.43	1.71	.93	1.00	1.00	.79	1.6	2.5	2.4	2.1
6	2.20	3.60	...	...	1.26	1.43	...	...	1.7	2.5	...	...

	Tunnel angle				Wall thickness				Septal count	
	#1	2	3	4	#1	2	3	4	#5	6
0	...	...	...	...	.012	.030	.025	.025	...	...
1	...	...	25°	20°	.015	.030	.030	.020	14	14
2	18°	10°	28°	19°	...	.030	.035	.025	19	17
3	27°	18°	33°	27°	.050	.050	.040	.030	19	19
4	28°	24°	42°	29°	.060	.060	.060	.050	20	19
5	...	29°	...	...	.080	.100	.090	.060	...	24
6	24°	39°	...	...	.080	.100	...	...	...	...

Specimens 1, 2, 3, 5, and 6 are shown on Plate 10 as Figs. 7, 8, 6, 9, and 10, respectively.

Discussion.—We have cut about 50 sections of this common species. Its distinctive features are its thickly ellipsoidal shape and its accelerated expansion and high outer volutions.

Berry identified this shell with *Schellwienia peruana* Meyer, the types of which were found at Tarma, Peru; but, as shown on page 486, that form is not only specifically but even generically distinct from the Bolivian shells. *Schellwienia* is a straight synonym of *Fusulina*, and *peruana* of Berry is therefore a homonym of *peruana* Meyer. Figures 1 and 2 of our Plate 10 show exterior views of the two immature shells figured by Berry and figures 4, 5, 9, and 10 show axial and sagittal sections cut by Dunbar from cotypes selected by Berry.

There is no other American species of *Triticites* which approaches this one in its rapid and accelerated expansion.

Distribution.—This is a very common species in Kozlowski's collections 2, 4, 5, and 7 at Yaurichambi and in his collections 13 and 16 at Apillapampa, Bolivia.

Triticites titicacaensis Dunbar and Newell, n. sp.

Plate 11, figs. 1-6.

Description.—A small, thickly ventricose species with regularly curved lateral slopes and neatly pointed poles, commonly 4.5 to 5.0 mm. in length and slightly over 2 mm. in diameter. Shells of this size have about 7 rather tightly coiled volutions.

The prolocula range in diameter from about 100 to 200 microns and are normally subspherical and have a wall thicker than that of the first volution. The spiral wall is rather thin, commonly measuring only 20 to 25 microns in thickness in the third volution and rarely exceeding 60 microns in the outer whorls.

Septa are rather strongly folded for this genus and septal loops are abundant even across the middle of axial sections. The tunnel is very narrow, commonly measuring between 15° and 25° in the third whorl and scarcely more in the outer volutions. It is bordered by massive chomata that are uncommonly heavy for a shell of this genus. In addition to the chomata, there is considerable epithecal material spread as a film on the wall and septa, all of which tends to give the shell a compact, dense appearance in thin section.

TABLE OF MEASUREMENTS.

whorls	Half length #1	2	3	4	Radius vector #1	2	3	4	Form ratio #1	2	3	4
0	.101	.042	.086	.064	.101	.042	.071	.064	1.0	1.0	1.2	1.0
1	.17	.10	.21	.14	.14	.07	.14	.10	1.2	1.4	1.5	1.4
2	.34	.18	.43	.29	.21	.13	.24	.17	1.6	1.3	1.7	1.7
3	.50	.34	.67	.46	.30	.18	.41	.29	1.6	1.8	1.6	1.5
4	.76	.57	1.23	.77	.44	.31	.66	.43	1.7	1.8	1.8	1.7
5	1.15	.86	...	1.20	.60	.47	.96	.63	1.9	1.8	...	1.9
6	1.57	1.23	...	1.57	.79	.64	...	.84	1.9	1.9	...	1.8
7	2.00	1.71	...	2.28	1.03	.93	...	...	1.9	1.8	...	...

whorls	Tunnel angle #1	2	3	4	Wall thickness #1	2	3	4	Septal count #5
0	...	...	...	...	.025	.025	.020	.025	...
1	14°	17°	19°	13°	.020	.015	.025	.018	14
2	10°	13°	9°	17°	.023	.015	.030	.020	14
3	16°	22°	29°	16°	.025	.020	.040	.024	18
4	14°	18°	21°	22°	.030	.025	.055	.020	20
5	17°	21°	...	32°	.030	.028	.063	.033	17
6	21°	26°	...	...	.055	.030	...	.045	21
7	...	...	...	...	.075	.037	...	...	...

Specimens 1, 3, 4, and 5 are illustrated on Plate 11 as Figs. 1, 4, 5, and 6, respectively.

PLATE 7.

Pseudoschwagerina uddeni (Beede and Kniker)

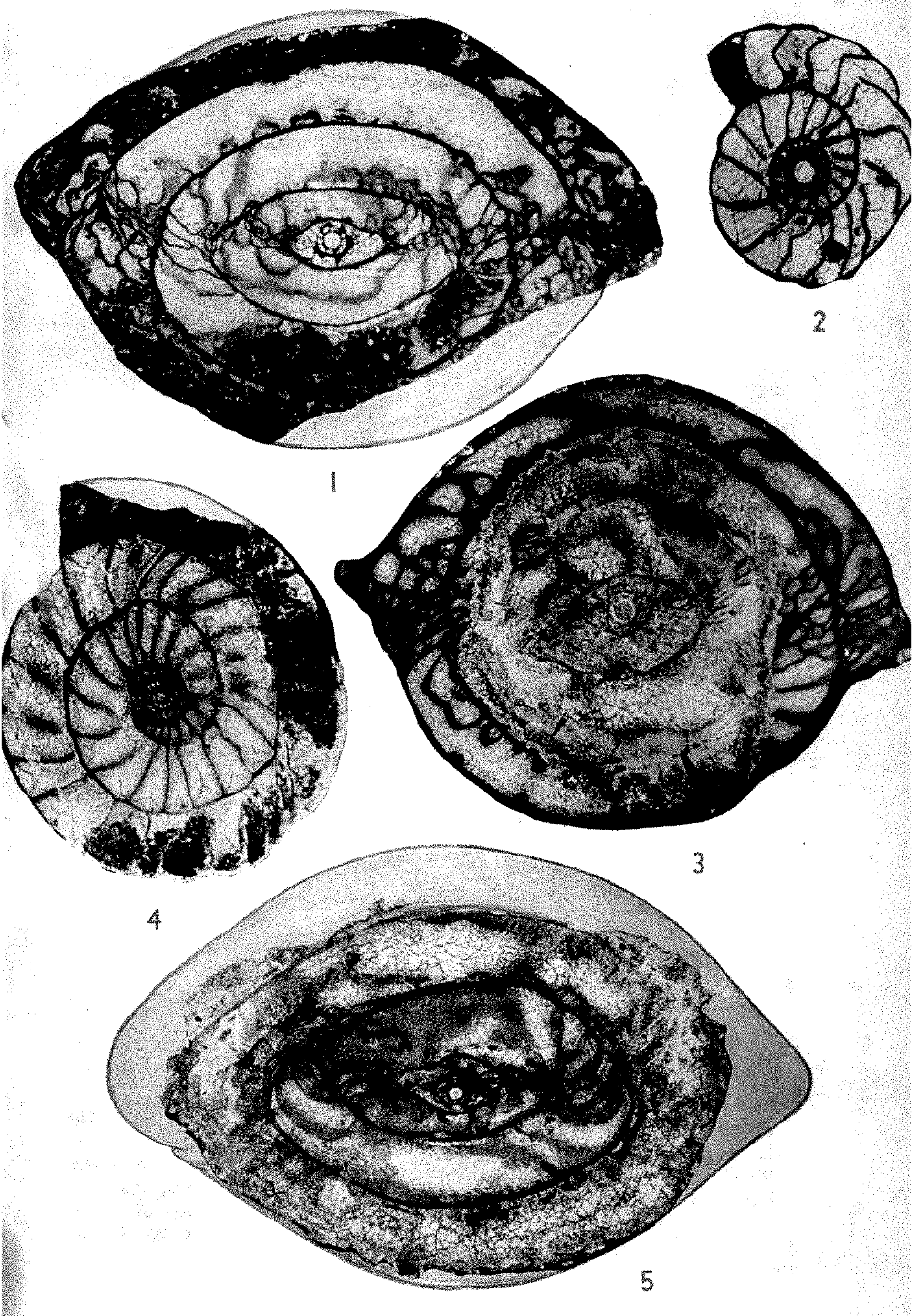
Fig. 1. Axial section (x 10). Y. P. M. 17443.

Fig. 3. Slightly oblique axial section (x 10) which foreshortens the axial length. Y. P. M. 17444.

Fig. 5. Axial section (x 10) with restored outer margin. Y. P. M. 17445.

Figs. 2, 4. Incomplete sagittal sections (x 10). Y. P. M. 17446, 17447.

All from Newell's collection 69-7 in bed 7 of the section at Cerro Pirhuate, Peru. This is about 2100 feet above the base of the Upper Paleozoic.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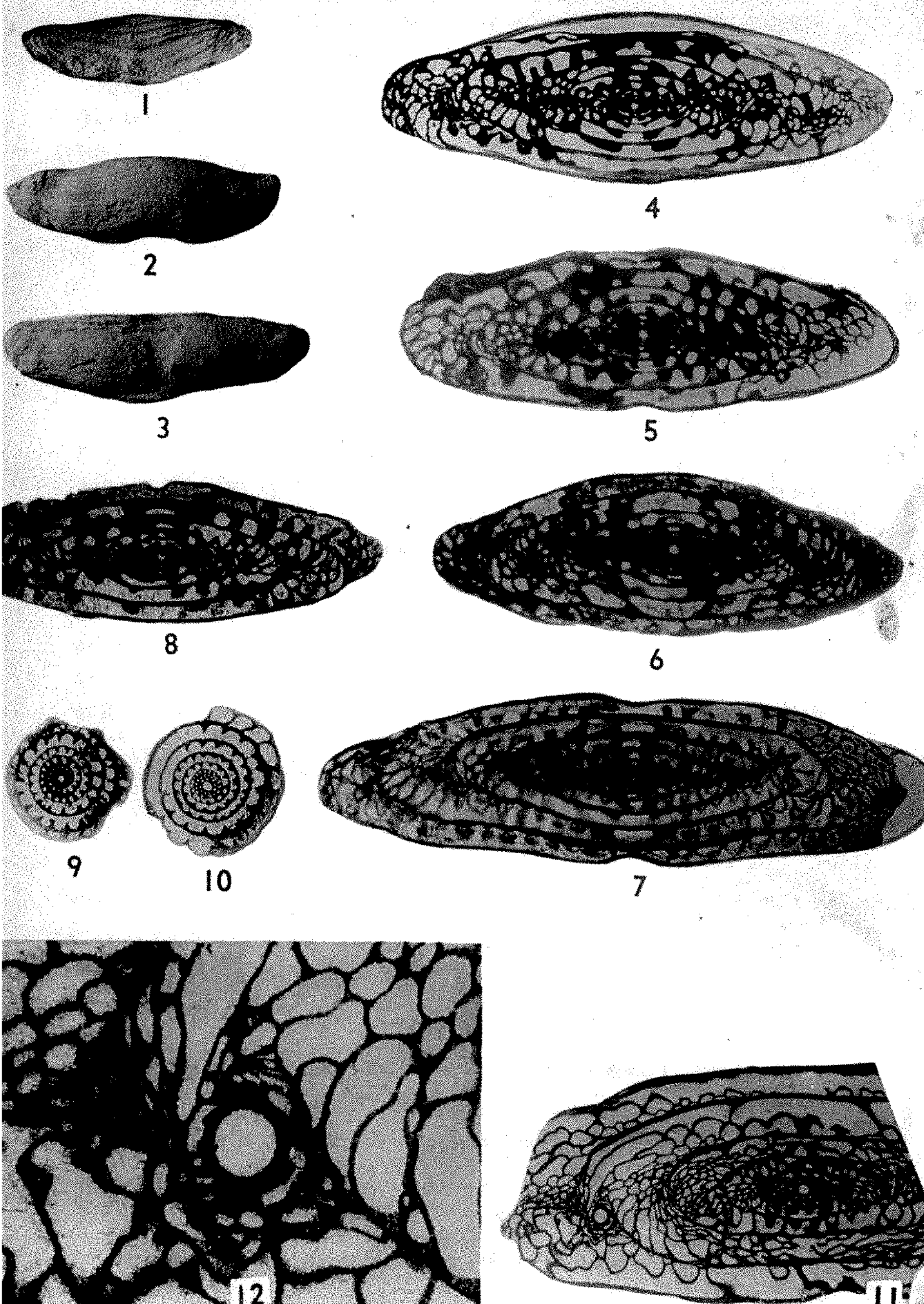


Triticites berryi

Discussion.—This species is distinguished by its close coiling, strong septal folding, heavy chomata, narrow tunnel, and the epithecal deposit especially in the juvenile whorls.

Distribution.—This species was found in Kozlowski's collections 2, 5, and 7 from Yaurichambi, and in his collection 16 from Apillapampa, Bolivia.

Triticites boliviensis Dunbar and Newell, n. sp.

Plate 9, figs. 1-11.

Description.—This is a slender species of medium-small size. The middle of the shell is subcylindrical or but slightly fusiform and the poles are rather bluntly rounded. It commonly attains a length of 7 to 8 mm. and a diameter of 1.6 to 2.0 mm., and at this size has 6 to 7 volutions. The shell shown by Fig. 8 on Plate 9 has 8 volutions and is larger than any other specimen seen which we would refer to this species.

The proloculum is small, commonly between 125 and 200 microns in diameter, and subspherical. The equatorial expansion is slow and gradual and the whorls low. The wall is thin, increasing gradually from about 20 microns thickness in the first volution to 30 microns in the third and 45 microns in the fifth. It shows distinctly an alveolar structure of rather fine texture.

PLATE 8.

Triticites berryi (Willard Berry)

Figs. 1-3. Paratypes (x 5) from Chulpapampa, Bolivia, in the collections of Johns Hopkins University.

Figs. 4-6. Paratype axial sections (x 10) from the same collection.

Fig. 7. Holotype axial section. This is the specimen figured by Berry as figure 6 of his plate 22.

Fig. 8. Axial section from Kozlowski's collection 7 at Yaurichambi, Bolivia.

Figs. 9, 10. Paratype sagittal sections (x 10) from the same lot as figures 4 to 6.

Schwagerina (?) *patens* Dunbar and Newell, n. sp.

Fig. 11. Axial section (x 10) showing at the left end of the penultimate whorl a young shell of the same species incorporated in the large shell. From Kozlowski's collection 1 at Yaurichambi, Bolivia.

Fig. 12. Enlarged detail (x 50) of the area about the young shell in figure 11.

The septa are nearly plane across the middle of the shell but are thrown into relatively loose, irregular folds near the poles, as indicated in Fig. 3 of Plate 9. Septal pores are common but very fine. The tunnel is low and rather wide, the tunnel angle increasing from about 40° to 50° in the third volution up to 55° or 60° in the fifth. Chomata are well developed in all but the outer whorl, but are rather slender.

TABLE OF MEASUREMENTS.

whorls	Half length				Radius vector				Form ratio			
	#1	2	3	4	#1	2	3	4	#1	2	3	4
0	.086	.05	.071	.071	.071	.05	.071	.057	1.2	1.0	1.0	1.2
1	.23	.20	.24	.27	.12	.10	.15	.15	1.9	2.0	1.6	1.8
2	.36	.45	.46	.44	.18	.18	.23	.23	2.0	2.5	2.0	1.9
3	.57	.90	.84	.91	.26	.28	.36	.36	2.1	3.2	2.3	2.5
4	1.07	1.50	1.57	1.71	.30	.45	.54	.51	3.5	3.3	2.9	3.3
5	1.85	2.25	...	2.43	.57	.65	...	.77	3.2	3.5	...	3.1
6	2.43	3.40	...	...	.76	.90	...	...	3.1	3.7	...	...

whorls	Tunnel angle				Wall thickness				Septal count		
	#1	2	3	4	#1	2	3	4	#5	6	7
0	...	...	...	...	.025	.020	.013	.019	...	...	...
1	35°	...	28°	22°	.020	.015	.021	.020	12	11	11
2	37°	25°	36°	45°	.025	.015	.020	.030	15	12	13
3	40°	35°	44°	49°	.029	.025	.030	.030	16	16	13
4	48°	50°	...	53°	.027	.030	.033	.040	17	19	17
5	56°	51°	...	...	.059	.043	...	.045	15	21	22
6	...	...	...	...	.040	.065	...	.045	...	...	...

Specimens 1 to 7 are illustrated on Plate 9 as Figs. 3, 7, 1, 4, 11, 9, and 10.

Discussion.—This small slender triticite is a conservative form and might be compared with Pennsylvanian rather than Permian species. There is considerable resemblance, for example, to *T. venustus* Dunbar and Henbest of Illinois and to *T. acutus* Dunbar and Condra from the Virgil series in Nebraska and Kansas. It is difficult to draw useful distinctions between such simple and conservative forms. But since the one before us is associated with Permian faunas and is from a distant continent, it seems wise not to apply to it the name of our Pennsylvanian species.

Distribution.—The types of this species are mostly from Kozlowski's collection 14 at Apillapampa, Bolivia, and there it

is associated with *Pseudoschwagerina kozlowskii* and *P. d'orbignyi*. It is also associated with these species in Kozlowski's collections 10, 11, and 12 from the same locality and is present in his collection 1 at Yaurichambi where it is associated with *Schwagerina patens*.

Triticites nitens Dunbar and Newell, n. sp.

Plate 9, figs. 12-16.

Description.—A minute species of 5 to 6 volutions which only attains a length of about 2.5 to 3.0 mm. and a thickness of 1 to 1.2 mm. Its shape is meloniform with convex lateral slopes and bluntly rounded poles.

The proloculum is minute, commonly between 100 and 150 microns in diameter. The spiral wall is thin and the volutions are closely coiled.

The septa are very gently folded except near the poles, and the tunnel is bordered by well-developed chomata.

TABLE OF MEASUREMENTS.

whorls	Half length				Radius vector				Form ratio			
	#1	2	3	4	#1	2	3	4	#1	2	3	4
0	.071	.071	.071	.071	.071	.057	.071	.057	1.0	1.2	1.0	1.2
1	.16	.23	.17	.20	.10	.11	.11	.10	1.6	2.0	1.5	2.0
2	.26	.36	.26	.37	.14	.17	.17	.16	1.8	2.1	1.5	2.3
3	.51	.53	.43	.58	.20	.23	.27	.31	2.5	2.3	1.5	1.8
4	.71	.79	.67	.96	.33	.36	.41	.37	2.1	2.1	1.6	2.5
5	1.11	1.13	1.08	...	.43	.44	.57	...	2.5	2.5	1.8	...

whorls	Tunnel angle				Wall thickness				Septal count
	#1	2	3	4	#1	2	3	4	#5
0	...	...	...	...	.013	.019	.025	.015	10
1	14°	16°	24°	17°	.014	.015	.015	.019	15
2	22°	20°	21°	30°	.025	.019	.020	.020	19
3	24°	26°	28°	31°	.035	.020	.030	.025	20
4	30°	32°	...	...	.025	.030	.030	.027	22
5	...	...	...	...	...	.040	.033	...	...
6	...	...	...	...	...	.034	...	...	...

Specimens 1, 2, 3, and 5 are illustrated on Plate 9 as Figs. 14, 13, 16, and 15, respectively.

Discussion.—One might suspect that these minute shells are merely juvenile individuals of one of the larger species. The

small size of its prolocula and early volutions would rule out most of the associated species. We have compared them closely with the inner whorls of *Triticites boliviensis* and the resemblance is close through the third volution, but in the fourth and fifth whorls *T. boliviensis* rapidly expands and by the end of the fifth is nearly twice as long as *T. nitens*. After careful study we are forced to conclude that this is a minute species. It was found sparingly in several collections but is not abundant in any of the material studied.

Occurrence.—This species is most common in Kozlowski's collection 16 from Apillapampa, Bolivia, and has also been found in collections 13 and 14 from the same locality. In collection 16 it is associated with *Schwagerina prolongada*, *S. steinmanni*, *Triticites berryi*, *T. patulus*, and *T. titicacaensis*; and in collections 13 and 14 it is associated with *Pseudoschwagerina kozlowskii* and *P. d'orbignyi*.

PLATE 9.

Triticites boliviensis Dunbar and Newell, n. sp.

Fig. 1. Axial section (x 10) of juvenile shell from Kozlowski's collection 10 at Apillapampa, Bolivia.

Fig. 2. Axial section (x 10) from Newell's collection 138 at Yaurichambi, Bolivia. Y. P. M. 17448.

Fig. 3. Axial and tangential slices (x 10) of specimens in the rock from Kozlowski's collection 14 at Apillapampa.

Figs. 4-7. Four typical axial sections (x 10) from the same collection as the last. Figure 4 represents the holotype.

Fig. 8. Axial section (x 10) of a specimen tentatively referred to this species, though it has more volutions and a greater size than the types. The course of the septa indicates that at the left end the shell is curving away and that end of the section is therefore somewhat foreshortened. From Kozlowski's collection 1 at Yaurichambi, Bolivia.

Figs. 9, 10. Sagittal sections (x 10) from Kozlowski's collection 13 at Apillapampa, Bolivia.

Fig. 11. Sagittal section (x 10) from Kozlowski's collection 10 at Apillapampa.

Triticites nitens Dunbar and Newell, n. sp.

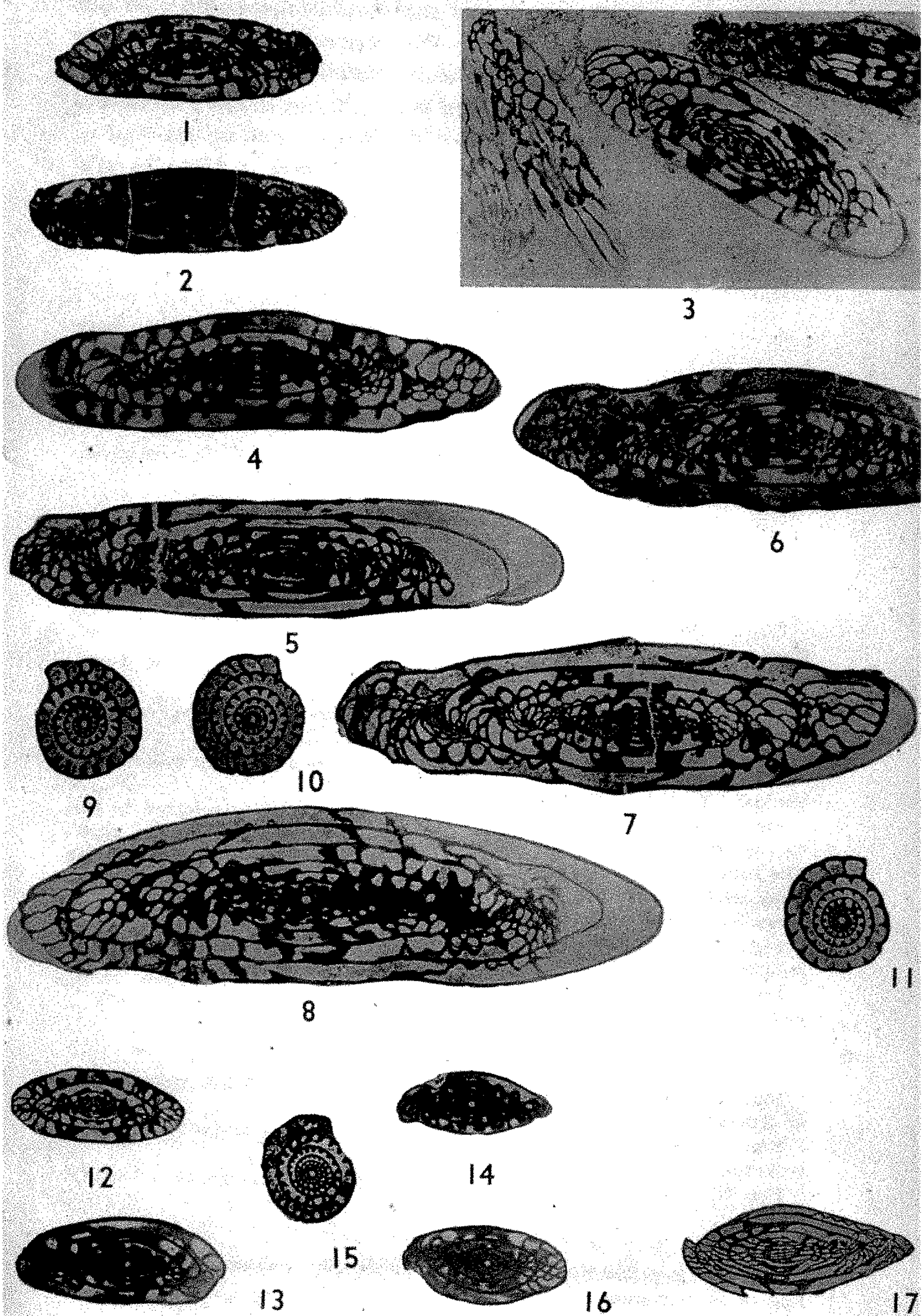
Fig. 12. Paratype axial section (x 10) from Kozlowski's collection 13 at Apillapampa, Bolivia.

Figs. 13, 14, 16. Holotype and two paratype axial sections (x 10) from collection 16 at the same locality.

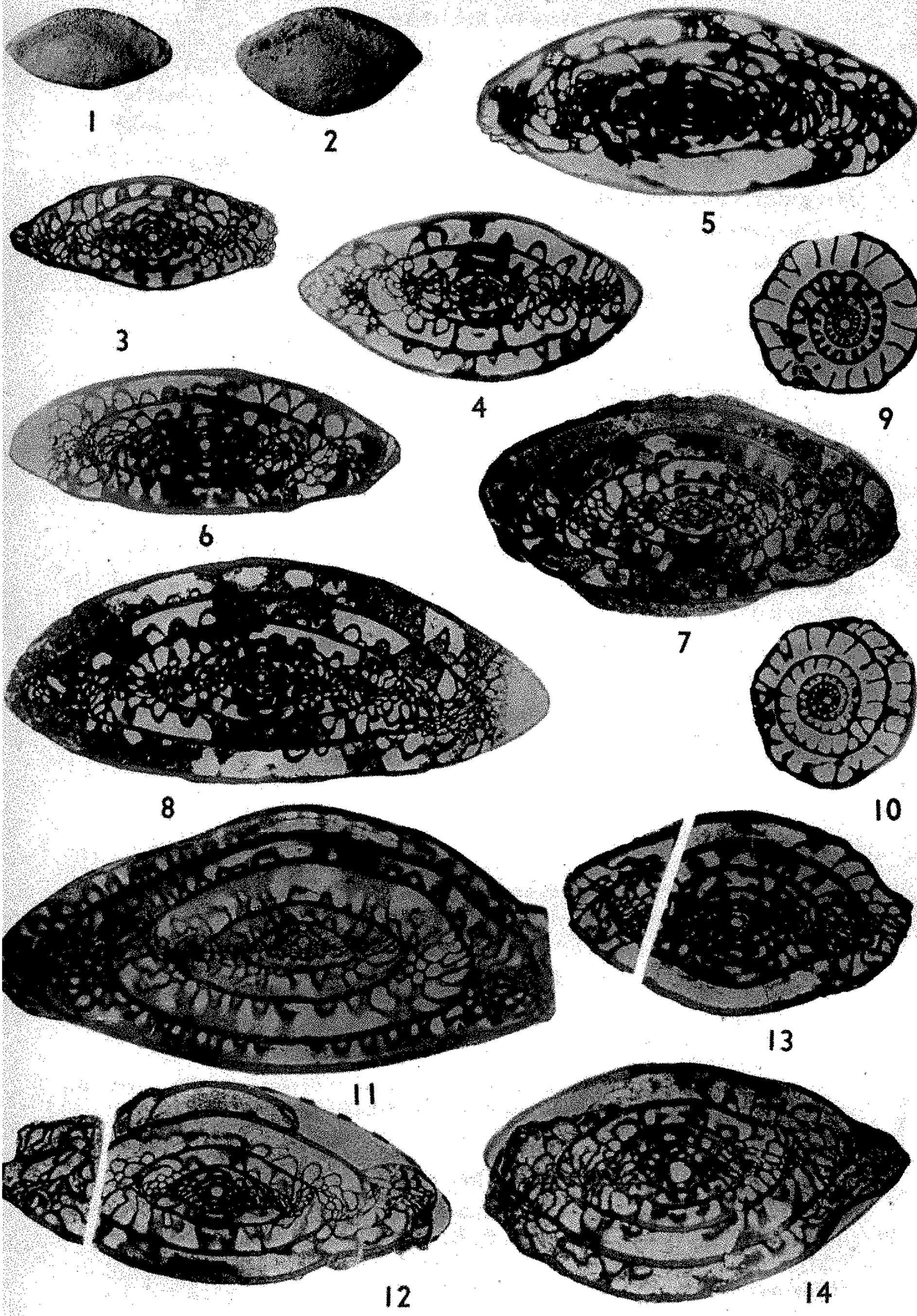
Fig. 15. Paratype sagittal section from collection 16 at the same locality.

Fusulinella peruana (Meyer)

Fig. 17. Reproduction of Meyer's original figure reduced to a magnification of 10 diameters.



Triticites boliviensis



Triticites patulus

Triticites opimus Dunbar and Newell, n. sp.

Plate 10, figs. 11-14.

Description.—A rather large, thickly fusiform species of 5 to 6 volutions attaining a length of 5 to 8 mm. and a diameter of 3 to 3.6 mm. The lateral slopes are convex and the poles obtusely rounded. There appears to be an unusual amount of irregularity in the shape near the poles.

The prolocula are rather large and show wide range in size with diameters ranging from about 200 to some 400 microns. The shell expands rapidly during growth and the volutions are uncommonly high. The spiral wall is thick and distinctly alveolar.

The tunnel is rather narrow and variable in width, with a tendency for the tunnel angle to reach its maximum in the fourth volution and decrease in the fifth. Chomata are present but are rather slender and are proportionately more massive in the first 2 or 3 volutions than in later ones.

The septa are rather widely spaced and are somewhat strongly folded for this genus. The holotype (Fig. 11 of Plate 10) shows uneven folds along the inner margin of the septa which are relatively strong and high in the last 1½ volutions but are weaker and lower in the inner whorls. This is a thick section and the septal loops appear more abundant than they do in normal thin slices.

PLATE 10.

Triticites patulus Dunbar and Newell, n. sp.

Figs. 1, 2. Exterior views of two immature shells (x 5) from Chulpapampa, Bolivia. These were figured by Berry as *Fusulina peruana* Meyer and are in the collections of Johns Hopkins University.

Fig. 3. Axial section of young shell (x 10) from Kozlowski's collection 2 at Yaurichambi, Bolivia.

Figs. 4, 5, 9, 10. Two axial and two sagittal sections (x 10) from Chulpapampa in the collections of Johns Hopkins University. These sections were cut by Dunbar from Berry's lot labelled "*Fusulina peruana* Meyer."

Figs. 6, 7, 8. Axial sections showing shells of different growth stages (x 10) from Kozlowski's collection 7 at Yaurichambi. The specimen represented as figure 7 is designated as the holotype.

Triticites opimus Dunbar and Newell, n. sp.

Fig. 11. Holotype (x 10) from Newell's collection 92-C from bed 8 of the section near Muñani, Peru. Y. P. M. 17454.

Figs. 12-14. Paratype axial sections from Newell's collection 92 in bed 51 of the section near Muñani. Y. P. M. 17455-17457.

TABLE OF MEASUREMENTS.

whorls	Half length #1	2	3	4	Radius vector #1	2	3	4
0	.10	.20	.14	.12	.10	.18	.12	.12
1	.34	.54	.30	.43	.20	.43	.19	.23
2	.37	.93	.80	.86	.43	.66	.31	.31
3	1.78	1.50	1.60	1.16	.80	.97	.50	.57
4	2.75	2.57	2.40	1.95	1.20	1.45	.89	.87
5	3.70	...	3.20	2.86	1.75	...	1.27	1.43
6	...	...	...	3.71	...	...	...	...

whorls	Tunnel angle #1	2	3	4	Wall thickness #1	2	3	4
0	...	...	...	...	.030	.040	.040	.035
1	...	23°	31°	22°	.045	.070	.030	.045
2	34°	18°	34°	28°	.070	.060	.030	.060
3	34°	30°	44°	40°	.070	.085	.050	.070
4	34°	59°	55°	38°	.108	.108	.070	.100
5	22°	...	45°	?	.130	...	.100	.130
6	...	...	...	?	...	...	...	.140

Specimens 1-3 are illustrated on Plate 10 as Figs. 11, 14, and 12, respectively.

Discussion.—In size and shape, and in its high volutions, this species resembles *Pseudoschwagerina kozlowskii*, with which it is associated, but it expands gradually and has well developed chomata and a relatively thick wall. It is unquestionably to be referred to *Triticites*.

It also resembles *T. patulus* in its rapid expansion, but differs notably from that species in its ontogeny, having a much larger proloculum, fewer and more loosely coiled early whorls, weaker chomata, and a smaller number of volutions at maturity.

Occurrence.—Found in the section near Muñani where it is rather common in bed 3 (Newell's collection 92-C). Also present in Kozlowski's collection 7 from Yaurichambi.

Fusulinella peruana (Meyer)

Plate 9, fig. 17; Plate 12, figs. 1-7.

Schellwienia peruana Meyer. Neues Jahrb. für Min., Geol. und Pal., Beil.-Bd. 37, 1914, p. 623, pl. 14, figs. 3a and b. (Not *Fusulina peruana* Berry, 1933.)

Original description (free translation).—"The shells are strongly inflated, 2.5 to 3.7 mm. long and 1.5 to 1.8 mm. thick.

The number of volutions appears to reach 6 at maximum, but commonly only 5 are present. The whorls are tightly coiled and the height of the volutions increases gradually from the inner to the outer. The wall is very thin, reaching only 30 microns in the outer whorl. The twice measured proloculum has a diameter of 60 microns. The septa are thick and but very slightly folded. The folding appears strongest in the axial region. A rather narrow tunnel is always clearly displayed, being bounded by strong chomata. The septal count in the single measured specimen is 15, 18, 21, 24 for the first 4 volutions, respectively. The increase in the number is so gradual that the septal curve is a straight line. Nothing could be seen of keriotheca."

Meyer's description was clearly based on inadequate material. He figured only one sagittal and one longitudinal section and the latter is somewhat oblique and does not cut the proloculum (our Pl. 9, Fig. 17). He stated that he counted the septa in only one specimen and measured the proloculum in only two.

Fortunately he located the source of his types in the section at Tarma and it is almost certainly bed 22 of Newell's section (page 387). The abundant fusulines collected from that bed by Newell are in all probability, therefore, topotypes of Meyer's species. On the basis of this material it is redescribed as follows:

Description.—A rather thickly fusiform species of 7 to 8 volutions commonly attaining a length of about 4.8 and a thickness of about 2.3 mm. The middle of the shell is very slightly inflated and the poles are rather bluntly rounded.

The proloculum is commonly between 100 and 150 microns in diameter and is spheroidal. The volutions of the shell expand gradually and rather slowly. The first whorl is almost spheroidal with a form ratio of only 1.2 to 1.3 and the shape changes gradually during ontogeny until the length is about twice the diameter at maturity.

The septa are nearly plane except near the poles where they are irregularly folded. Septal pores are abundant, at least in the outer whorls, but are rather obscure. The tunnel is moderately high and of moderate width, as shown in the table of measurements.

The wall has the structure typical of *Fusulinella*, the diaphanotheca appearing as an almost clear layer between the

TABLE OF MEASUREMENTS.

whorls	Half length #1	2	3	4	Radius vector #1	2	3	4	Form ratio #1	2	3	4
0	.07	.05	?	.07	.07	.05	?	.07	1.0	1.0	...	1.0
1	.14	.09	.12	.17	.12	.10	.09	.14	1.2	...	1.3	1.2
2	.26	.21	.24	.30	.17	.16	.14	.20	1.5	1.3	1.7	1.5
3	.43	.36	.36	.47	.27	.26	.21	.29	1.6	1.4	1.7	1.6
4	.79	.63	.46	.73	.40	.39	.33	.41	2.0	1.6	1.4	1.8
5	1.30	.99	.79	1.01	.59	.59	.47	.57	2.2	1.7	1.7	1.8
6	1.55	1.47	1.13	1.37	.77	.77	.63	.73	2.0	1.9	1.8	1.9
7	2.00	2.10	1.57	1.85	1.04	1.04	.86	.95	2.0	2.0	1.8	2.0
8	...	...	2.15	...	...	...	1.10	...	...	...	2.0	...

whorls	Tunnel angle #1	2	3	4	Wall thickness #1	2	3	4	Septal count #5	6
0	...	...	...	...	.020	...	...	.015	...	...
1	...	...	...	...	...	.015	.015	.015	11	13
2	16°	24°	22°	21°	.020	.015	.020	.030	15	18
3	13°	20°	21°	15°	...	.043	.030	.035	17	23
4	24°	16°	23°	17°	.043	.030	.030	.035	21	25
5	24°	21°	25°	26°	...	.043	.043	.050	22	27
6	30°	27°	25°	25°	.043	.070	.070	.070	26	32
7	37°	34°	32°	17°	.060	...	.060	.043	...	...
8	...	...	38°	...	...	...	.036	...	...	...

tectoria, as shown on Fig. 5, Plate 12. The inner tectorium is thinner than the diaphanotheca but the outer tectorium comprises fully half the thickness of the wall and is not clearly delimited from the chomata which are thick and wide.

PLATE 11.

Triticites titicacaensis Dunbar and Newell, n. sp.

Figs. 1, 2. Holotype axial section (x 10 and x 20) from Kozlowski's collection 7 at Yaurichambi, Bolivia.

Figs. 3, 6. Paratype axial and sagittal sections (x 10) from Kozlowski's collection 16 at Apillapampa, Bolivia.

Figs. 4, 5. Paratype axial sections (x 10) from Kozlowski's collection 2 at Yaurichambi, Bolivia.

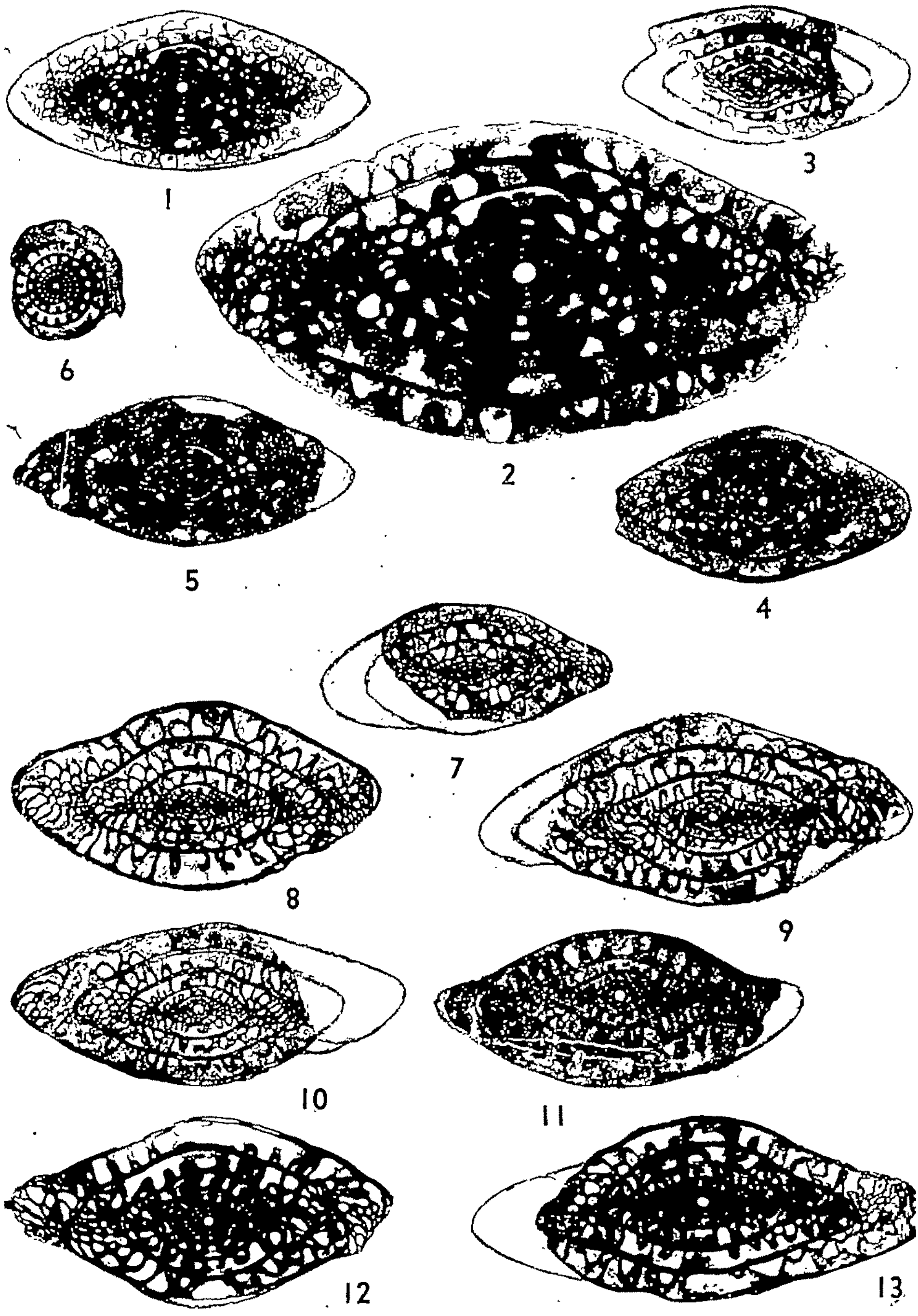
Schwagerina muñaniensis Dunbar and Newell, n. sp.

Fig. 7. Paratype axial section (x 10) from Kozlowski's collection 2 at Yaurichambi, Bolivia.

Fig. 8. Holotype axial section (x 10) from Newell's collection 92 at the summit of the Permian section near Muñani, Peru. Y. P. M. 17449.

Figs. 9-11, 13. Paratype axial sections (x 10) from the same collection as figure 8. Y. P. M. 17450-17453.

Fig. 12. Axial section (x 10) from Kozlowski's collection 7 at Yaurichambi, Bolivia.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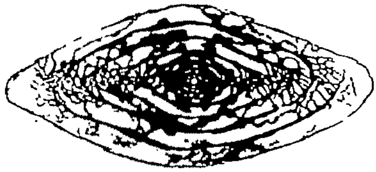

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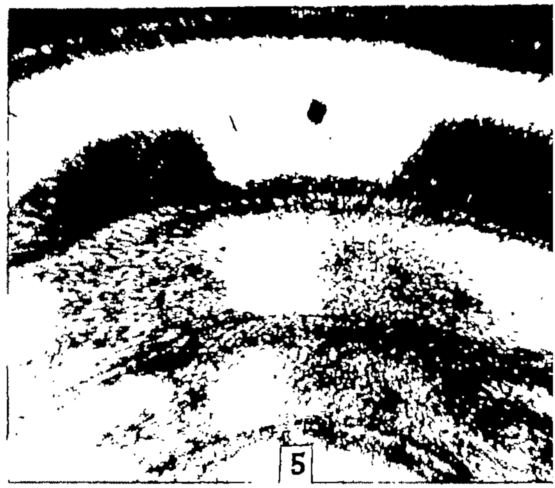

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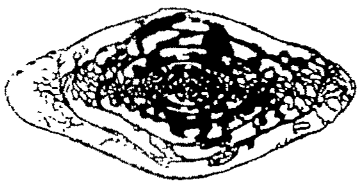

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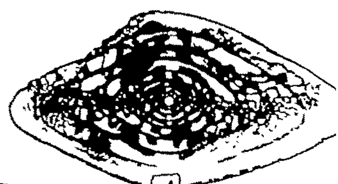

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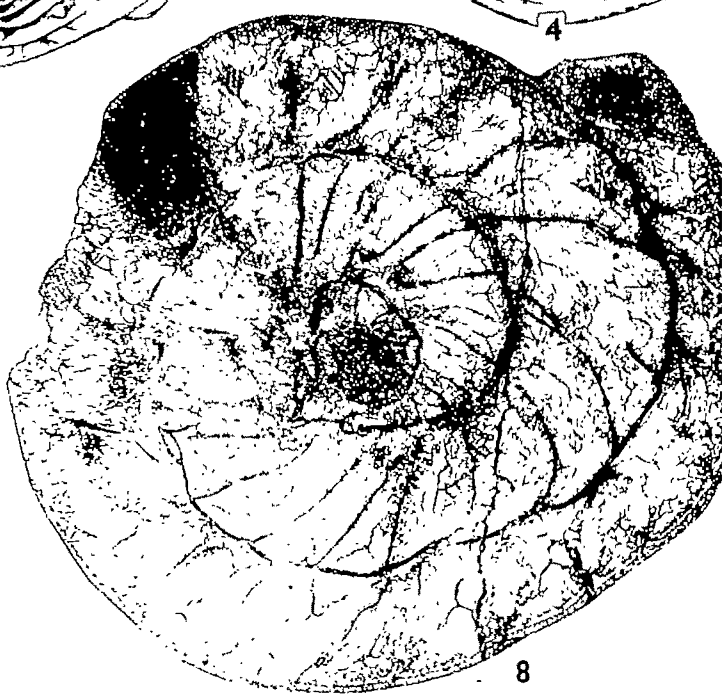

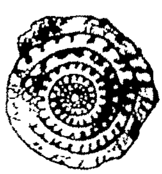

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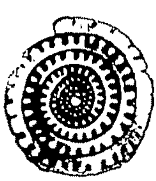

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8

Specimens numbered 1 to 6 are illustrated by Figs. 1-4, 6, and 7 on Plate 12.

Discussion.—If our shells are topotypes, Meyer must have based his species upon immature individuals, since he observed only 5 or 6 volutions and indicated a maximum length of 3.7 mm., whereas ours commonly attain 7 to 8 volutions and have a length of 4.8 mm. Support for this inference may be seen in the fact that in the fifth and sixth volutions our shells agree closely with the dimensions given by Meyer. Our measurements of the prolocula appear to differ from those of Meyer who found the diameter to be only 60 microns in the two specimens examined. But his illustration (his figure 3b) clearly shows a larger size. When allowance is made for the fact that this figure is enlarged 16 diameters, it indicates a proloculum having an inside diameter of about 68 microns and an outside diameter of about 115 microns. If we assume that Meyer measured the inside dimensions, as some students have done, then the discrepancy disappears. Meyer also indicated a thinner wall than we have observed, but if he was dealing with immature shells this difference also is explained.

This is an uncommonly large species for the genus *Fusulinella* and its wall attains an exceptional thickness due to the massive inner tectorium.

The form which Willard Berry described under the name of "*Fusulina peruana* (Meyer)," from the Lake Titicaca region, is both generically and specifically distinct and is redescribed in this study as *Triticites patulus*, n. sp.

Occurrence.—Found near the top of the Tarma group (=Des Moines series) in the section at Tarma, central Peru (bed 22 of Newell's section).

PLATE 12.

Fusulinella peruana Meyer.

Figs. 1-4. Axial sections (x 10) of topotypes from bed 22 of Newell's section of the Tarma group at Tarma, Peru. Y. P. M. 17459, 17460.

Fig. 5. Enlargement (x 150) of a part of the section shown in figure 4. This can be identified with an area in the second to fifth volutions in the upper half of that figure.

Figs. 6, 7. Sagittal sections (x 10) from the same lot. Y. P. M. 17461.

Pseudoschwagerina cfr. *P. uddeni* (Beede and Kniker).

Fig. 8. Sagittal section (x 10) of a specimen from collection 69-7 in bed 7 of Newell's section at Cerro Pirhuate, Peru. Y. P. M. 17458.

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DESERT RIPPLES.

RONALD L. IVES.

ABSTRACT. Relatively large, slightly arcuate ripples, arranged very roughly en echelon, with crests supporting vegetation and troughs plated with caliche, cover several thousand square miles of desert land in the basin-and-range physiographic province of North America. Physical structure and probable origin of these features are here outlined.

INTRODUCTION.

DURING the progress of field work in the western part of the United States from 1928 until the present, the writer has noted large arcuate ripples, with tops supporting a moderate stand of vegetation and troughs plated with caliche, in a number of desert areas. Strong development of these features is found in the Salt Lake Desert, of Utah; the Lechuguilla Desert, of Arizona; and the Altar Desert, of Sonora, Mexico.

General appearance of desert ripples, as seen from an airplane at 20,000 feet MSL. (15,600 feet terrain clearance), in the Salt Lake Desert is shown in Plate 1. Local residents in the Salt Lake Desert area call these features, appropriately, "axle busters."

More than forty months of service at an Army post in the Salt Lake Desert made possible continued observation of desert ripples, and their relation to local environmental conditions.

DESCRIPTION.

Desert ripples, in the Salt Lake Desert, are from 30 to 500 feet long, and from 10 to 36 inches high. Spacing between crests of ripples varies from 10 to 50 feet. All ripples in a given level area have about the same dimensions and spacing. General shape of the ripples is roughly arcuate, with minor local variations near clumps of vegetation or other surficial obstructions.

Crests of the ripples support a moderately dense sage growth, the components being small, but of considerable age, indicating dwarfing. Trough floors are plated with caliche. Sectioning of a number of ripples discloses that the crests are underlain by a mass of roots and humus, which merges

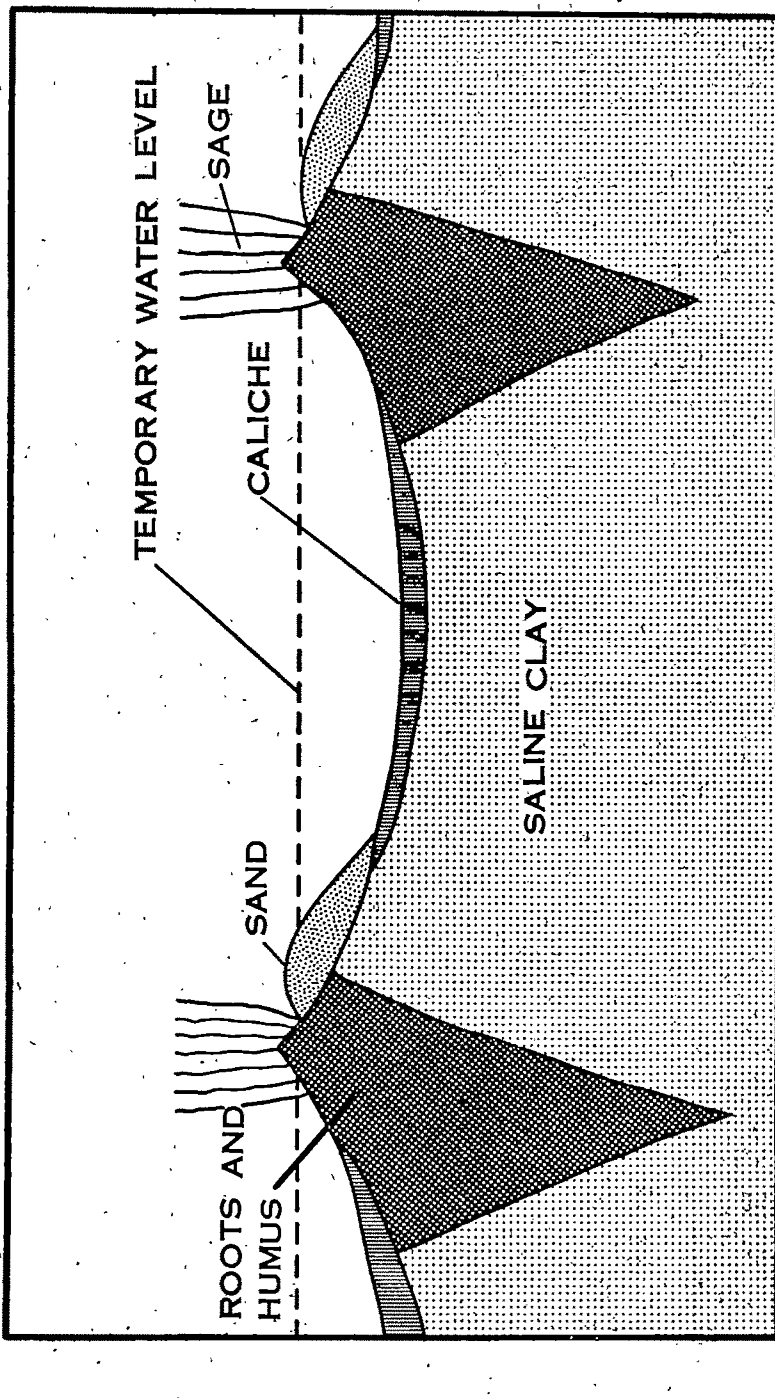


Fig. 1. Generalized section of a rippled area, showing subsurface arrangement of components. Note the relation of the sand with reference to the offsetting of the ripple crest.

gradually into the saline clay beneath the troughs. A generalized section across a pair of ripples comprises Text Fig. 1, which is not to scale. Note, in this figure, the offsetting of the ripple crest, and its relation to the accumulation of sand.

During wet seasons (late spring in the Salt Lake desert), the troughs of these ripples fill with water to the temporary water level shown in Text Fig. 2. At least a part of this filling, in the Salt Lake Desert, is due to upwelling of subsurface water (probably from a brine horizon 18 feet below the general land surface), as is indicated by the chemical nature of the water.

ORIENTATION.

Studies of the orientation of desert ripples over a wide expanse of sage and clay flats east and southeast of the Bonneville Salt Flats disclosed that their orientation, away from large dunes and inselbergs, is quite uniform, the chords of the ripples trending approximately N 60°E. In the near vicinity of dunes, the ripple crests follow the approximate trend of the dune crests. Near inselbergs, stacks, volcanic necks, and similar large topographic features, the trend of the ripple crests is disturbed in a manner suggesting a local transition from the regional trend (N 60°E) to one roughly radial to the structure. The extent of this disturbance of crest trend is approximately three times the height of the topographic feature that it surrounds.

APPARENT ORIGIN.

Field evidence strongly suggests that desert ripples are aeolian features. Ripple orientation indicates that these features were produced by winds blowing from approximately N 30°W. (330° azimuth). Deviation of ripple crest trends near surficial obstacles is in almost exact accord with conventional aerodynamic theory, the ripples in disturbed areas being perpendicular to streamlines about these obstacles. Arrangement of drift sand (Text Fig. 1) and offsetting of ripple crests both support this reasoning, as do the concordance of dune and ripple-crest trends.

Seasonal flooding of the area, leading to plating of the ripple trough floors with caliche and to leaching of the crests help to explain the distribution of vegetation in the rippled areas. Once established, such vegetative distribution tends

to be self-perpetuating, as the ripple crests are somewhat protected from aeolian and other erosion by sage cover; and the troughs, made sterile by caliche deposition, are subject to deepening by wind erosion during dry seasons.

Thus, according to all ordinary geologic evidence, which is supported by conventional aerodynamic theory, desert ripples are aeolian features.

CONFLICT OF EVIDENCE.

Trend of ripples indicated that the wind forming them, in many parts of the Salt Lake Desert, came from approximately 330°. This conclusion is supported by the local direction of dune migration, the offsetting of ripple crests, and the location of sand accumulations in the ripples.

In almost diametric contradiction, local wind records, kept by coöperative observers, indicate that the prevailing wind in these same areas is from the southeast quadrant, central azimuth 135°.

Observations in the Lechuguilla Desert, southwestern Arizona, having shown that the trend of ripples similar to those in the Salt Lake Desert is normal to the local prevailing wind, it became apparent that a thorough checking of the evidence from the Salt Lake Desert was necessary.

CHECKING OF EVIDENCE.

Introduction.

The conflict of evidence, outlined above, indicated either that dunes in the Salt Lake Desert migrated to windward, and local vegetation was pneumotropic (a palpable absurdity), or that some part of the previous reasoning or observation was wrong.

Geologic Evidence.

The possibility that the ripples in the Salt Lake Desert were formed during a previous climatic regime, and were preserved by their cover of vegetation, was considered. As many of the older roads in this area have been partially obliterated by ripple structures, this possibility may be ruled out. Several roads used as recently as 1925 are blocked, and the ruts filled in, by ripples. A few ripples cut through in 1942 have already (1946) started to regenerate the missing sectors.

As these ripples somewhat resemble longitudinal dunes, reported from the Indian Desert,[1] small piles of brick dust and powdered graphite were placed at strategic locations among the desert ripples. Visits to these areas during the ensuing two years disclosed that index material was transported along an axis normal to the ripple chords, in the direction indicated by the offsets of the ripple crests (left to right, Text Fig. 1). Attrition of index material prevented longer observation. A similar concordance of evidence was noted at the old Gilson Smelter (east side of the Dugway Mountains, Tooele County, Utah) where finer slag particles have been blown slightly more than a mile toward the southeast since smelting operations ceased in 1895.

These tests indicated that there were no serious errors in the geologic evidence or its interpretation.

Meteorological Evidence.

Checking of the accumulated meteorological data from the general area, and personal visits to several of the coöperative observers indicated that, while the distribution and number of coöperative stations left much to be desired, the work was being conducted diligently and competently. There appeared to be no reason to question the substantial correctness of the existing data.

Establishment of an extensive network of recording and reporting meteorological stations in the area, in connection with other researches, permitted a thorough check of wind behavior in the rippled area.[2]

Summarized results of these measurements show that the *prevailing wind*, which is the *wind direction most often reported*, was from the southeast quadrant, as was previously shown by the reports of coöperative observers. Wind frequency for a typical day, in the rippled area, is shown in Text Fig. 2.

Assumption that wind speed is constant during the hour following each speed measurement is not entirely justified, but

[1] Cornish, V.: 1897, *On The Formation of Sand Dunes*, Geog. Jour. 9, 278–309.

[2] Descriptions of methods, equipment, and findings are contained in the following reports, now undergoing clearance for publication: Ives. R. L. *Remote Reporting Equipment for Wind Speed and Direction; Continuous Wind Recorders; Surface Winds in the Salt Lake Desert; Reduction of Wind Data*; (with Kroona, E. L.) *Errors in Wind Speed Measurement.*

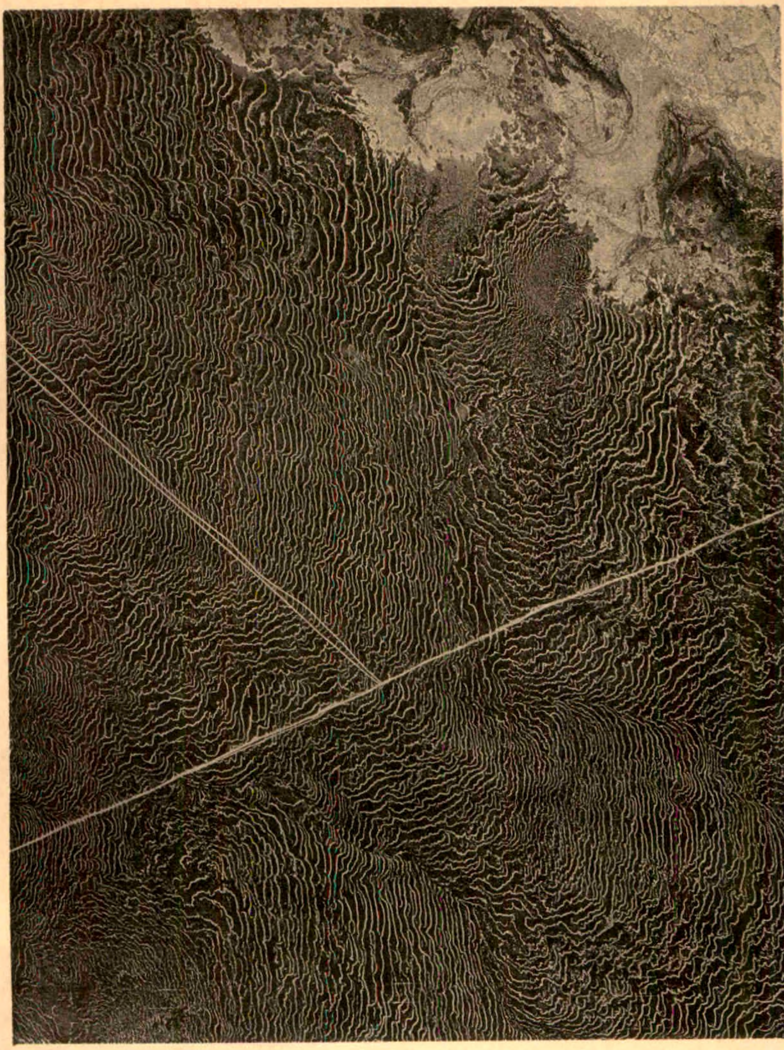


Plate 1. Desert ripples in the Salt Lake Desert, about five miles northeast of Granite Peak, Tooele County, Utah, as seen from an airplane about 15,600 feet above the terrain. Top of this picture is north. The scale is 1″=1000 feet.

the error due to this extrapolation is compensating, hence use of the extrapolation is permissible when a *large* number of observations is concerned. When this extrapolation is made, reported wind speeds are considered as hourly travel figures.

Plotting of the hourly wind travel, as found above, by directions, in the form of a wind rose, discloses that the *dominant wind*, which is the *direction from which the greatest travel is reported*, determined from the same instrumental data as were used for Text Fig. 2, is NNW. This is shown in Text Fig. 3 (left). As will be obvious from this chart, the prevailing wind, SE, is substantially cancelled by an opposing wind travel from the NW. Cancellation of opposing wind travels along each axis gives the *net winds* for the period, which are shown in Text Fig. 3 (right). It will be noted that the "working" wind, as shown by this figure, falls in the same octant as that indicated by ripple orientation.

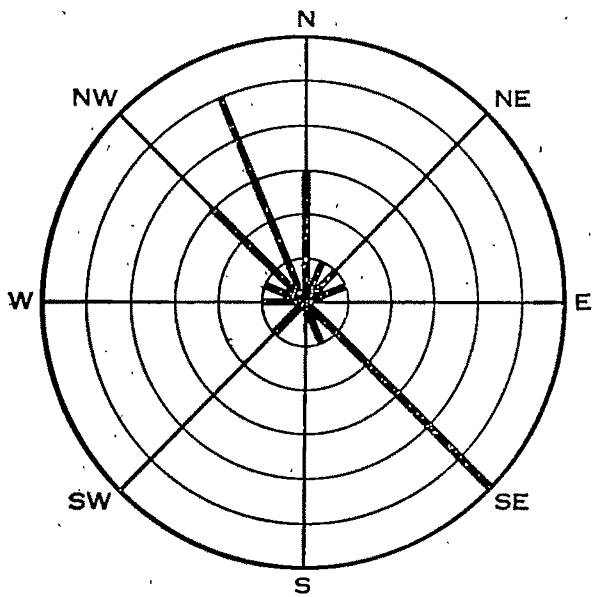


Fig. 2. Wind frequency rose for a typical day in the Salt Lake Desert. Each circle represents one hourly report.

The ability of the wind to do work being a function of the

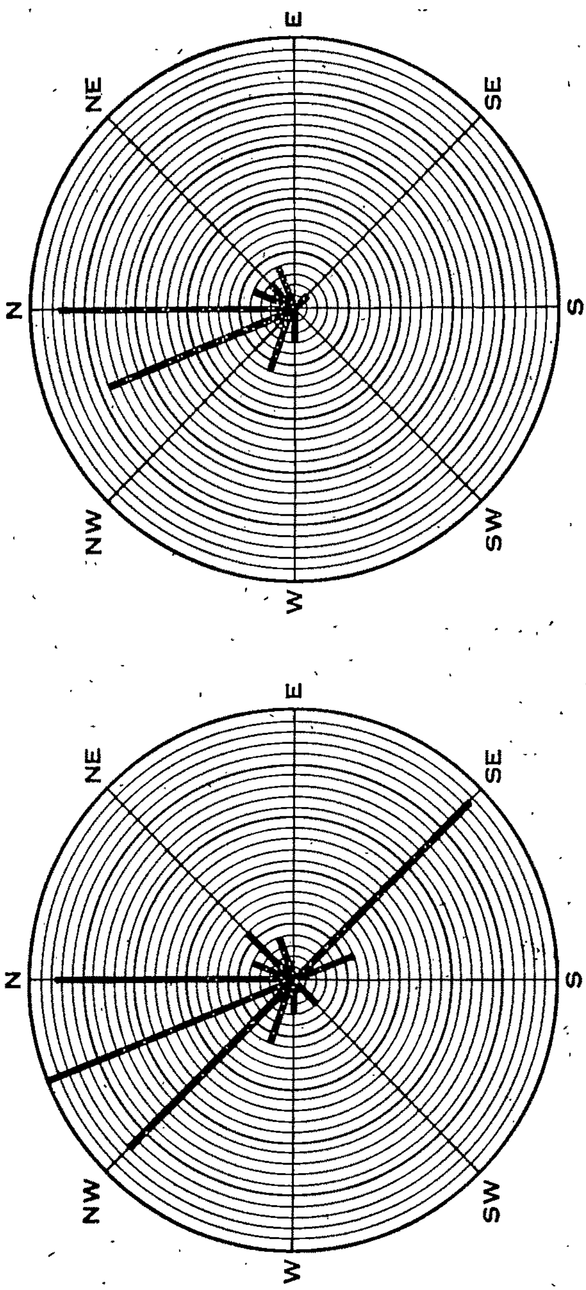


Fig. 8. Wind travel rose for a typical day in the Salt Lake Desert (left), and net wind travel for the same period (right). Each circle represents one mile of wind.

square of the wind speed, an attempt to reconcile the geologic and meteorologic evidence, using dynamic wind values, was made. ***Resultant dynamic wind***, which is the vector sum of the individual dynamic winds, the azimuth of which is the reported azimuth, and the magnitude the square of the reported speed, was determined for a year for each of several stations. The resultant dynamic wind direction for a typical day (based on the same observational data as Text Fig. 3), was found to be 355°. Comparison of computed resultant dynamic wind directions with normals to ripple chords indicated an error of not more than 16°, but the computed azimuth of the resultant dynamic wind was always greater than that of the normal to the ripple chord.

Recomputation of the resultant dynamic wind direction, omitting data from periods when the desert was covered with snow, or too wet to permit wind transport of clay, caused a reduction of the wind azimuth of approximately 10°. Checking of the wind records disclosed that during a considerable part of the middle spring, when the desert was too wet to permit wind erosion, the major wind travel was from the southwest (this is a normal seasonal effect).

The normal to the average azimuth of the ripples within a 100 yard circle just southwest (lower left) of the area shown in Plate 1 was found to be 290°. Computed resultant dynamic wind azimuth for the same site, where wind observations were recorded hourly for 25 months, was 294°. In a second site, northeast (upper right) of Plate 1, the normal to the average ripple chord had an azimuth of 331°. Computed azimuth of the resultant dynamic wind at this site, where records were kept hourly for 14 months, was 324°. Several other comparisons, based on less extensive wind records, or data of lesser inherent accuracy, gave similar concordances. In all of the above comparisons, wind data from intervals when wind erosion was impossible (soil wet or snow-covered) were omitted from the computations.

Further refinements of the recording and computing methods, such as the use of a continuous dynamic wind recorder, and the weighting of the computations by means of a continuously recorded soil motility factor would theoretically give more accurate results. Use of these theoretically better methods was not attempted because of the stupendous amount of com-

putation involved. Such refinements, in all probability, would be a waste of time at present, due to the inherent shortcomings of present-day meteorological equipment and methods.[8] The possibility also exists that there are long-term cyclic, progressive, or random variations in the actual azimuth of the resultant dynamic wind which were not found during the course of this (geologically) short study.

CONCLUSIONS.

It is apparent, from the geologic and meteorologic findings here presented, that desert ripples are small transverse clay dunes, the structure being partially stabilized by vegetal cover on the ripple crests and by caliche plating of the trough floors. Orientation of the ripple chords is transverse to the resultant dynamic wind operating during that part of the year when wind erosion is not inhibited by snow cover or soil wetting.

Resolution of the apparent conflict of evidence noted in the early part of this study indicates that the orientation of sand dunes, desert ripples, and similar features is primarily determined by the resultant dynamic wind direction in the area concerned. From this orientation, the resultant dynamic wind can be determined with a fair degree of accuracy. Orientation of these features, however, does not necessarily bear any relation to the prevailing wind direction, and this wind direction cannot, in general, be determined with any assurance by reference to geomorphic features.

It is most unfortunate that the term *prevailing wind*, which has a strictly temporal meaning in meteorology, has been used, by many geologists and engineers, to designate the direction of the wind responsible for the orientation of aeolian features, such as sand dunes. This confusion has been strengthened, in many areas, by the coincidence of prevailing wind (term used in the meteorological sense) and the resultant dynamic wind, which is the wind direction actually responsible for orientation of aeolian features.

ACKNOWLEDGEMENTS.

The writer is indebted to Sgt. (now Lt.) Rita K. Wilkinson, T/3 Evelyn L. Kroona, T/4 Dorothy Lankin, T/5 Stella C.

[8] Ives, R. L., and Kroona, E. L: *Errors in Wind Speed Measurements*, op. cit.

Pieklo, and Pfc. Agnes J. Mernin for the major part of the reduction and computation of the wind data used in this study; to Drs. S. W. Grinnell and Carey Croneis, of the N.D.R.C., for helpful discussions of field evidence and problems; and to Dr. P. G. Worcester, of the University of Colorado, for a critical reading of this manuscript.

Dugway Proving Ground,
Tooele, Utah.

ICE-CONTACTS AND THE MELTING OF ICE BELOW A WATER LEVEL.

JOHN H. COOK.

ABSTRACT. Sedimentary beds that have been banked against motionless submerged ice, preserve a mold of the ice surface. The edges of glacial terraces and platforms, and the sides of kettle-holes when so molded, are called ice-contacts. In plan, they may exhibit an irregularity that is characteristic; in profile, they present a variety of forms not all of which can be easily identified.

A study of excavations made in the more obscure types has demonstrated that many submerged ice-faces had been melted back at the base before melting was arrested by deposition of the sediments.

The explanation of extended, hummocky, and gently-sloping contacts is furnished by that property of meltwater whereby heat generated at the surface of a pool is forthwith conveyed to the bottom, thus melting the ice at the base.

Undermelting is followed by fracture; and sections so broken off are set afloat, to melt away above water level, often without leaving a trace.

IN a letter written in 1872 Louis Agassiz made reference, probably the earliest, to what would today be called ice-contacts. "There are everywhere," he wrote, "stratified terraces without border barriers (since these were formed only by the ice that has vanished)" (E. C. Agassiz, 1885). The terraces referred to lay on the sides of a valley, and to visualize the ice that had vanished was not difficult for one who had seen stratified drift banked against living ice "as on the borders of the glacier of Grindelwald." Yet, until the last few years of his life (too late to prepare his revised opinions for publication), Agassiz was unable to identify as ice-contacts the abrupt bounding slopes of the osar in the midst of which he lived. Although, eventually, he came to understand osar as a product of the meltwaters "that accompanied the break-up of the geological winter," rather than as glacial drift modified by waves and tidal currents, he held to the then prevailing belief in a contemporary marine submergence of the New England coast, and considered that the many lake basins and cranberry bogs were to be explained by the former presence of stranded icebergs. Evidently, a multitude of ice-contacts in a region "so little broken" as eastern Massachusetts, presented a problem quite different from that presented by those which occasion valley-side terraces.

In a paper published in 1873, N. H. Winchell attributed the steep sides of a stratified deposit at St. John's, Ohio, to confinement between the walls of a gully or cleft in the ice-front; and the following year T. F. Jamieson (1874) introduced the idea of slumping: "a mass of gravel reposing against the side or end of a glacier would lose its support when the ice melted away, and, falling down in a slope, would assume the form of a steep-sided mound."

The concept of ice-contact having found its way into geologic literature, there remained the difficulty of applying it. Seventy years ago the influence of the Noachian legend was stronger than it is today; and many of the miraculous powers formerly ascribed to waves and tidal currents, were being uncritically accepted as normal for streams of meltwater. Given a warming climate and a great body of ice, it was easy to conjure up images of torrents and floods which transcended experience. The ability of these imaginary rivers to perform the seemingly impossible could always be invoked to explain otherwise inexplicable features: meltwater streams were not bound by the laws which govern modern streams. Broad valley-bottoms, now threaded by underfit streams, were (and, occasionally, still are) interpreted as the paths of those supposedly greater glacial rivers that had removed vast sections of outwash and flood-plain. In spite of their often dimpled and scalloped margins and their frequently perfectly flat surfaces, terraces were generally accepted as remnants of stream deposits which, earlier, had filled the valleys from side to side.

Against this preconception, appreciation of the evidence for lingering ice-masses made headway but slowly. William M. Davis, fresh from a study of contact phenomena in the Boston district (1890; 1892a), failed to recognize similar phenomena in the Catskill valley (N. Y.), and described a series of icebound deposits as the remains of a dissected delta (Davis, 1892b). This instance of the misinterpretation of obvious ice-contacts is not unique in the literature of the past fifty years: it is cited merely because, there being no need to labor the point by multiplying references, a selection is called for. It will serve to illuminate the fact that some difficulty has always attended attempts to recognize ice-contacts in field studies.

Some ice-contacts are characteristically irregular in plan: so unlike the bluffs bordering stream-cut trenches that they can

be read from the contours of a topographic map with a considerable degree of confidence. Examples of this type attracted the attention of R. D. Salisbury of the New Jersey survey (Salisbury, 1894): recognizing that the deep reëntrants and prominent spurs of certain terraces represented interfingering with stagnant ice, he called the terraces, *kame-terraces*. (For the projecting spurs he invented the objectionable term *crevasse fillings*.)

But not all ice-contacts are so self-evident: they are sometimes smooth and nearly straight for long distances. And in profile they exhibit a great variety of form: precipitous, outcurved at the base, gently sloping and, as an exaggeration of the usual kame-terrace margin, greatly extended beyond any leveled surface with which they may be associated. In the days when judgment was necessarily based almost wholly on external form, many of the more obscure contacts escaped identification: the smooth shelving type looks much like a beach; and the extended type is hardly to be distinguished from mounded deposits formed on the melting out of heavily burdened basal ice when stagnant and not laved by standing water (till heaps).

Several years ago, gravel pits were opened in some hillocks that the writer had previously interpreted as "kames resulting from slump" (Cook, 1924); the sections proved that the hillocks were an integral part of an unmodified extended ice-contact, and indicated that a critical examination of the many excavations made during the past quarter of a century in the glacial deposits of the Hudson valley might lead to a better understanding of ice-contacts in general.

The structures studied were in bedded sands and gravels exposed along terraces and platforms (sand plateaus), and in kettle holes. (No openings were found within areas of kame-complex.) Ordinarily, the dip of terrace beds was towards the assumed position of contemporaneous ice, but in several instances the dip was away from the ice. Indications of disturbance due to glacial movement against the contacts were sought but not found; it may be assumed, therefore, that this paper deals exclusively with contacts made against ice which was stationary.

It was observed that crests are sometimes sharp, sometimes smoothly rounded, and sometimes practically nonexistent (the flat top of the deposit becoming a gentle slope with no marked

line of transition). These distinctions, probably, are unimportant, except that slumping was noted only in association with sharp crests. Some surprises were furnished by contacts having a rounded crest; chief among them being the discovery that an elongate, lenticular hill on the eastern side of the Hudson opposite the city of Albany (not infrequently mistaken for a drumlin) is a "platform" of glacial gravels whose sides and ends are of extraordinary smoothness, and whose flattish top is so reduced that it is inconspicuous. The slopes of this hill are (on a much larger scale) much like those shown in Plate 1 which have been chosen to exemplify the smooth rounded type of contact.

The gravels composing this ridge mark the point where a stream coming off from (or out of) the glacier, contributed to the building of an extensive terrace a part of which can be seen in the distance (A). The deposit was made between arching and deeply undermelted walls of ice. The gentle slope over which winds the road to the pit (B) is underlain by sands continuous with those of the ridge: it is *a part of the contact that ran under the edge of the glacier*—an edge that, locally, may have been separated from the main body of ice and come afloat.

The sharp crested type of contact is illustrated in Plate 2. In this example the slopes have undergone so little later modification that they may be accepted as the almost perfect mold of a submerged ice-surface as it was on the day when the basin that trapped the sediments was drained. At its top, the contact is more nearly vertical than it is below, where it descends in long, sweeping curves, then gradually flattens out to form the floor of a trough. This trough is in stratified sand as far back as the buildings; and it is pitted by a kettle. The form of the ice-surface here preserved may be described as strongly convex, deeply undermelted, and with a pillar of basal ice remaining in a subglacial recess. Since the sands of the trough's floor give place to bedrock not far beyond the kettles, there is no reason to believe that this part of the glacier margin was afloat.

Although the accumulation of sediments under a glacier has long been recognized as a possibility, it has seldom been invoked to explain particular physiographic details other than eskers, the picture generally accepted being that of a solid body of ice in contact with its basement everywhere, except for such tunnels as may have developed. In 1931 S. A. Andersen (1931) sought

to explain the topographic expression of undisturbed stratified deposits associated with stagnated marginal zones (kames, kame-complexes and pitted plains) as "largely a cast of the under surface of the ice at the time when the deposition ceased" (p. 613). The theory advanced by him to account for spaces beneath a zone of stagnated glacier will be mentioned later on; at this point it is desired only to emphasize the fact of undermelting. Every exposure examined confirmed an early impression that surfaces in some degree convex must be regarded as a normal development of the melting of submerged ice. That the base of the convexity was frequently carried under the glacier for a considerable distance became evident when it was seen that below what, usually, has been considered the foot of a contact, there might be a continuation of the sediments running out to form flatter ground.

The principle of physics involved in what I have here called undermelting is simple and well enough understood; but because (if a limited acquaintance with the vast literature is sufficient basis for judgment) glacial geologists have overlooked, or lost sight of that principle, I propose to discuss it somewhat fully.

The melting of ice is a problem in conversion of energy. Part of the solar "radiation" falling upon rock or water is converted into heat; that falling upon ice or snow when at the critical temperature of 0° Centigrade, is not: it is converted directly into the *energy of state* or of molecular freedom (the so-called "latent" heat of earlier physics). Thus no heat is produced during the change from solid to liquid. Ice and water at 0° Cent. will rest in contact without bringing about a change of state in either. Excess heat in the air (*i. e.* more than is required to maintain the temperature at 0° Cent.) when applied to a surface of ice, is withdrawn from the system of temperature exchanges and merely converts the solid into a liquid at the same temperature; when applied to the surface of a meltwater pool, it raises the temperature of a thin film *slightly* (never as much as 4° Cent.). The reason for this limitation on the "absorption" of excess heat is that just below 4° Cent. the point of greatest density is reached, and the surface film *sinks*. If it were possible to observe the process, a continuous rain of small masses would be seen detaching itself from the surface film and descending towards the bottom: having attained a density of 1.000,123 (the density of water at 0° Cent. being

taken as 1), these masses are no longer supported by internal tensions of the liquid. In time, enough of this heavier water will collect on the floor of a pool to move slowly down a slope; and, if the slope guides it to the side of an ice mass, its excess heat will be wholly expended in melting the ice. Becoming lighter, it is displaced upward. Thus a circulation is set up whereby excess heat is carried from the surface of a pool to the base of the ice-wall, where it becomes energy of state.

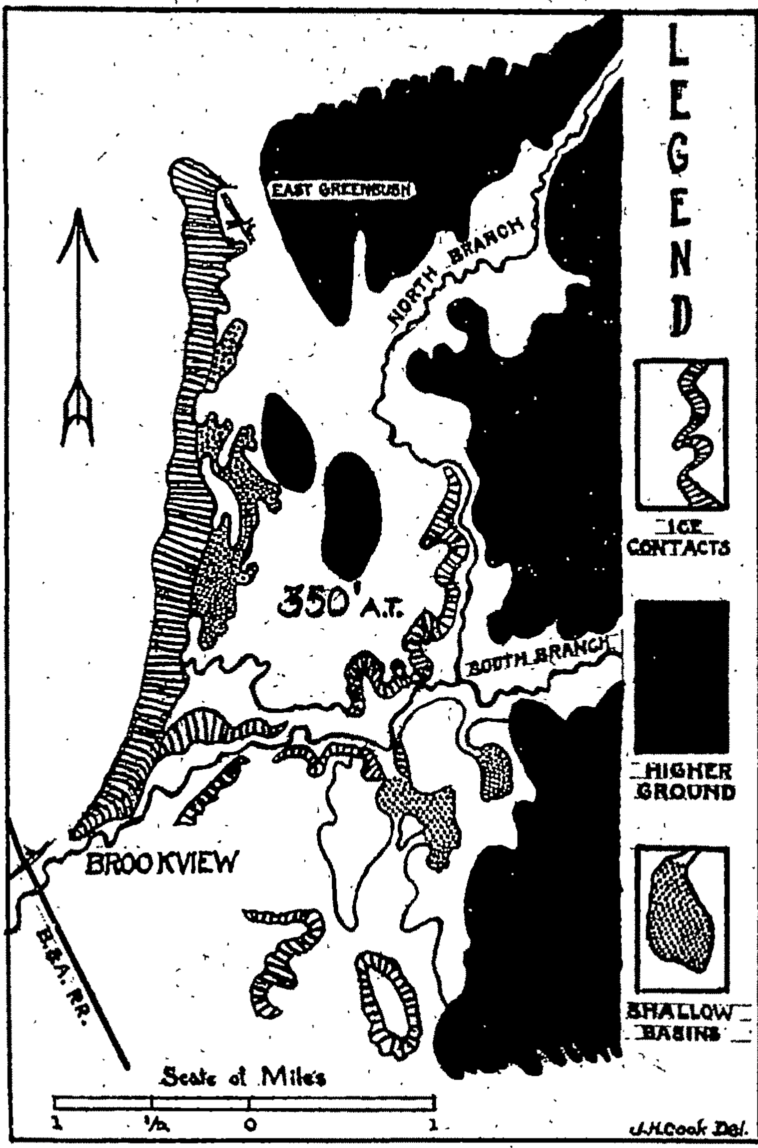
This unique property of ordinary water (called to the attention of geologists by W. O. Crosby in 1902) can be readily demonstrated in the laboratory. But to assess its efficacy as an agent in undermelting large bodies of the Pleistocene glaciers is not easy, because the only basis for an inductive study is supplied by the legitimate inferences that may be drawn from the form of ice-contacts and the structure of the bedding which they limit.

As a class, contacts on deltas and terraces present the simplest features. Of the many excavations made in these, two only gave any evidence that the glacier-faces had continued to melt back after sediments had been banked against them; and in each case the mold was in cobblestones. It is inferred that gravel, sand, and (especially) rock-flours banked against submerged ice, effectually insulate it. In general, then, contacts represent *a particular stage* in the enlargement of an icebound basin: the stage at which enlargement happened to be arrested. Logically, therefore, there must have been a basin filled with meltwater before sediments entered the pool: it is not possible to fill a hole until there is a hole to fill. The theory advanced by S. A. Andersen (1931) seeks to account for *all* the topographic forms assumed by undisturbed sediments associated with stagnant ice, by assuming that subglacial streams (beginning with esker tunnels) would "escape [through stagnant ice] more easily to the ice-border"; that the out-of-water ice would melt down "almost to the water table," at which time "a tendency to lift occurred *in the whole border zone*." (Italics mine.) No barriers to free run off being postulated, there were, on this assumption, no icebound lakes: only "a major water table which sloped more or less in the direction of flow," [a water table that]"may be treated as an ordinary water table in sand and gravel." Due to the tendency to lift "there came to be a space underneath the stagnant ice filled with rushing and irregularly

streaming water." "Thus there is . . . no limit for the breadth of the tunnels underneath the ice." (pp. 612-613.) Of several valid objections that might be urged against this conception, the only one calling for notice in connection with the present inquiry, is that it fails to take account of lateral melting. *Pari passu* with lowering of the ice-surface there is necessarily a melting back of the sides, as a consequence of which basins are formed between ice and hill-slopes. During the very considerable time interval between the first day of stagnation, and reduction of the glacier "almost to the water table" these basins must be presumed to have increased in size. If we are to have a sediment filled basin as an end product, we must have not only a preëxisting basin but also a process competent to enlarge it below the level of standing water. The latter we have endeavored to supply.

Land topography, varying permeability of different parts of the ice and the unequal distribution of enclosed rock débris are factors that, locally, control lateral ablation; so that here and there, between hill-slope and glacier, basins that *hold* water will form, as well as channels that carry it. The great size attained by some of these basins before they were filled by sediments is proof of two things: 1, that they existed for a very long time (since beneath a water plane there is no evaporation, and the only excess heat, other than that supplied by the lithosphere, comes from *the surface* of streams and pools); and 2, that the confining glacier *was solid* and was held against its basement by gravity (since, for so long, it continued to be a water-tight dam). Clearly, Andersen's hypothetical picture of "rushing and irregularly streaming water" filling "a space underneath the stagnant ice" cannot apply to any stage of ablation earlier than the latest, when locally the glacier was "melted down almost to the water table" (and then to valley-bottoms only). But *lateral basins were in process of development through all the preceding stages* that followed stagnation.

Ice-contacts are seldom as simple and smooth, for any great distance, as the one shown in Plate 2. More often the slope is diversified by mounds and dimples sometimes extending so far from the crest that, without exposures, it would be difficult to believe that they constitute an extension of the contact. In the present survey, undisturbed sediments, molded above by a roof



Text Fig. 1. Map of the northern part of the Schodack lateral terrace (Woodworth) showing the western ice-contact and its unusual prolongation along the edge of the Moordener kill valley. Other contacts outline the sites of residual ice-masses; and stipple indicates where shallow basins were left by the melting out of ice believed to have been afloat until fixed in position by accumulating sediments.

of ice, appeared consistently at pits made in such extended contacts; and slumping, as understood and described by Jamieson, would seem to have been confined to those few points where beds dipped away from the glacier.

Though only one true subglacial deposit (not connected with a terrace contact) was discovered, there can be little doubt that, in especially favorable situations, undermelting will result in the formation of deep pockets and blind galleries. That the most instructive examples of molded sediments which had filled such pockets, always occurred where the water had been deep in comparison with its depths on either side along the line of contact, cannot be regarded as fortuitous. Meltwater warmed to the temperature of greatest density responds to gravity not only by sinking, but also by moving down a slope once it has reached the bottom. It might be expected, therefore, that the greatest expenditure of excess heat would occur against ice encountered in the deeper parts of a pool.

A case in point is found near the southwestern corner of the Troy (N. Y.) quadrangle where a stream called the Moordener Kill cuts across a glacial deposit which Woodworth (1905) named the Schodack (kame, delta) lateral terrace (see Text Fig. 1). North of the kill there is a fingerlike protrusion of the ice-contact nearly a mile in length. The projection, beginning at the level of the neighboring glacial plain, *declines towards its tip*; its stratification, now exposed, is continuous with that of the terrace and, obviously, it was not built into an open channel-way or cleft in the glacier, like an accordant-level "spur" or "crevasse-filling" (of Salisbury's original kame-terrace), but into a pocket in the face of the ice, and under an ice roof which slanted to the southwest. This unusual feature occurs *precisely where the general line of contact crosses the bottom of a preglacial valley.* While he was surveying the Champlain and Hudson valleys, Woodworth's primary interest was to detect evidences of ancient water-levels, and he found the smooth slope at the base of this ice-contact: "suggestive of a water level"; its extension along the north rim of the Moordener Kill valley: much like a spit.

(Another blind-tunnel filling descends from the south end of a glacial terrace, along the north bank of Patroon's creek in the city of Albany. Competent geologists have expressed the belief that this protrusion is an "esker.")

Within the area covered by Text Fig. 1, there are, in addition to the "spitlike projection," details of the topography that merit attention. It will be observed that the consequent course of (postglacial) Moordener Kill has been "induced" by a series of kettle holes. During deposition of the sediments (and for a considerable time after the local water table had dropped), a mass of ice lay against higher ground along the eastern (inner) margin of the deposit. Other masses persisted from the confluence of the two branches to the outer edge of the terrace. There is nothing to suggest that any of this ice was ever lifted off from the basement. There are, however, other shallower depressions floored by stratified sand; and, though surface indications would admit of their being interpreted as sags due to the melting of buried ice, the undisturbed bedding of the floor is proof that the contained ice was afloat until held in place by accumulating sediments. Since wasting eventually causes a floating ice-block to rise above the warmer bottom water, ablation is thereafter confined to the surface exposed above water level; and it may be dissipated without leaving any trace. But when deposition ceases (or the water-table falls), an unmelted remnant of such a block may lie on the sedimentary beds, eventually to leave a patch of till, or a boulder or two, in the hollow that it had occupied. If the ice was clean, no evidence of its existence would remain except the depression.

The Schodack terrace was built up in large measure as the delta of a (forced drainage) glacial stream discharging through the valley of the North Branch; the greater part of the section north of Moordener Kill is a plain having an elevation above sea level of about 350 feet, and terminating westward at an ice-contact. The 340 foot contour shows a notable failure to build up to plain level along the line of contact. Here (and in most of the other cases studied) failure to develop an even crest is associated with evidences of undermelting; and it is inferred that sags in a crest result from the former presence of floating sections which had broken off. Fracturing, subparallel to the ice-face, followed by detachment of the overhang, would appear to be a necessary accompaniment of deep undermelting. Together these processes furnish a consistent theory of the enlargement of lateral basins.

Probably every terrace yields a fairly complete record of the degree to which the original basin was cleared of ice.

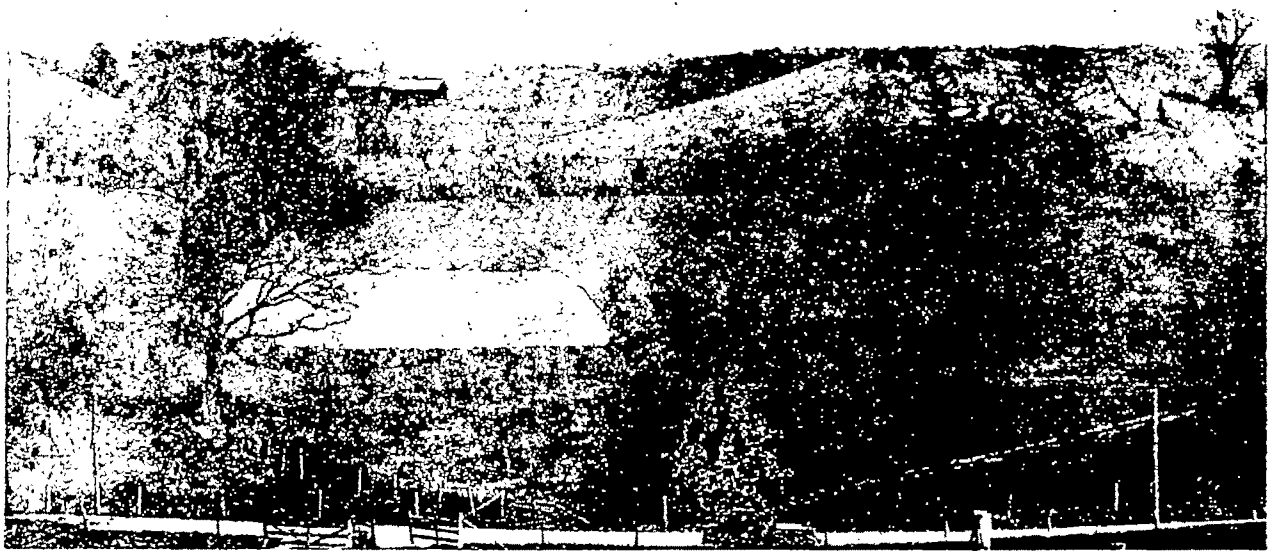
A

Ridge six miles south of the city of Hudson, N. Y. showing a smooth-crested contact. View looking south along the edge of a discontinuous terrace (on the left), to the building of which a stream coming off the ice at this point contributed. The flat ground in the middle distance is the floor of a lake.

B

A nearer view of the same ridge showing the long gentle slope between the observer and the pit which is a continuation of the ice-contact, the sediments having been deposited under overhanging ice. Excavation of the coarser gravels has been abandoned because the sand under the slope followed by the road is cleaner and better sorted.

From New York State Museum Bulletin No. 331.



View northward from ridge pictured in plate 1. The sharp crest at which the glacial terrace ends, is not due to slumping of the contact slope which continues down and across the trough on the floor of which there is a kettle-hole in stratified sand. A group of trees in line with the barns, locates the kettle.

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AGE OF THE CANADIAN KOOTENAY FORMATION.[1]

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ABSTRACT. The stratigraphic ranges of the species comprising the flora of the Kootenay formation in the Blairmore area of southern Alberta do not indicate a Jurassic age. Actually more genera, generally considered to be characteristic of the Jurassic, occur in the flora of the Blairmore and equivalent formations than in the flora of the older Kootenay formation. The Blairmore flora, which is correlated with a flora in the Kome beds of Greenland, and which includes practically all the known species of the Kootenay, is marked by the first appearance of dicotyledons, and is inferred to be of Aptian age. The close affinity of these two floras strongly suggests a Barremian or late Neocomian age for the plant-bearing part of the Kootenay formation in its type area.

INTRODUCTION.

IN a recent paper by R. W. Brown (1946, pp. 240-241) it was proposed to unite a basal part of the Kootenai formation of Montana to underlying beds that were correlated with, and included in the Morrison formation. In Montana these so-called Morrison beds had provided a few freshwater invertebrates, scattered fragments of vertebrates, and fruits of *Chara*. The faunal evidence was tentatively accepted as indicative of a Jurassic age both by C. A. Fisher (1908, p. 30) and W. R. Calvert (1909, p. 24), who worked respectively in the Great Falls and Lewistown coalfields. More recently W. A. Cobban (1945, p. 1269) on the evidence of *Chara* and ostracoda stated that "the age of the beds must be Kimmeridgian and possibly younger."

The enlargement and redefinition of the Morrison formation to include a basal part of the Montana Kootenai can be regarded only as a new grouping of beds that may be more in accord with lithological sequence or more useful to the field geologist. Formations are primarily only beds or groups of beds, united on the basis of lithology for geological mapping or other purposes, in which no important time-breaks in sedimentation have been detected. Individual formations, therefore, if they represent a sufficient interval of time may contain more than one flora or fauna, and may even be in the nature of pas-

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sage beds from one geological system to another. The Ravenscrag formation in southern Saskatchewan, for example, as originally defined (Davis, N. B., 1918 p. 11; Fraser, F. J. *et al.*, 1935, p. 39; Berry, E. W., 1935, pp. 4-7) carries an Upper Cretaceous flora and fauna in its basal part and a Paleocene flora in its upper part. Similarly the Blairmore formation in southern Alberta carries one flora throughout most of its thickness, and another flora in its uppermost several hundred feet. This palaeontological factor of formations is ignored by some geologists who assume that a formation must contain only a single flora or fauna, in spite of the truism that many formations transect chronological horizons.

In a sedimentary sequence of beds comprising a formation interruptions of the nature of erosional unconformities may occur without destroying the concept of lithological unity, defined for that formation, or violating the principle of essentially continuous deposition. Local features of this kind are very common in the form of channels at the base of sandstones or coarser clastics in non-marine sediments. In the case of more widespread erosional unconformities it is ultimately the judgment of a palaeontologist that will determine whether the break is too important to be included within the limits of a single formation. Where the plane of an eroded surface of major magnitude so nearly parallels the bedding planes as to be classified as a disconformity it may commonly escape detection by the geologist, and be included within the limits of a single formation. However, once its presence has been detected, it necessarily destroys the unity of that formation, and it must become the boundary between separate formations. Such hidden disconformities are particularly likely to occur at times of recession of an inland sea when the strand lines were undoubtedly oscillatory in their movements. Environmental conditions at such times were, moreover, probably critical for many kinds of both land and sea life, with resultant meagre fossil records, so that disconformities might long escape detection. An example of a recently discovered disconformity of this kind is that recorded by W. A. Cobban (1945, p. 1291) in the Jurassic formation of Montana, formerly known as the Ellis, and lying between Cobban's Swift and Rierdon formations. Another good illustration of a hidden disconformity in what were originally regarded as "Passage Beds" from the Kimmeridgian to the Aptian is afforded by Jurassic-Cretaceous sequence that

includes the Speeton Clay of England (Spath L. F. 1924, pp. 80-81). The disconformity in this instance embraced the uppermost Kimmeridgian, the Portlandian, Purbeckian, Infra-Valanginian and lowest Valanginian beds. Palaeontology and not lithology must be the criterion for the recognition of such disconformities.

STRATIGRAPHIC SETTING OF THE KOOTENAY.

The Kootenay formation, originally and loosely defined by J. W. Dawson (1886, p. 2) as the "Kootanie series" for strata containing a specific flora, was first differentiated on a lithological basis as a formation by W. W. Leach (1912, pp. 194, 195). Later its stratigraphic limits were emended by B. Rose (1917, pp. 109, 110) who redefined its contact with the overlying Blairmore formation. The formation, about 750 feet thick in the Blairmore area, consists of alternating sandstones, shales, and coal seams, the sandstones being grey, commonly coarse-grained and cross-bedded, the shales, dark, commonly sandy and carbonaceous.

The overlying Blairmore formation, 2000 feet or more thick, has its base generally marked by a conglomerate, 10 to 80 feet thick, which is locally present in valleys or channels eroded into the Kootenay. The succeeding Blairmore beds according to Rose are red, green and a few grey to black, sandy shales, interbedded with grey sandstones, generally in zones from 1 to 10 feet thick, although occasionally 50 feet, together with conglomerate at irregular intervals throughout and as lenses in the sandstone.

J. S. Stewart (1919, p. 28) described the contact of the basal conglomerate of the Blairmore with the Kootenay as "conformable and in most places the conglomerate grades into sandstone upward and downward, and in the eastern part of the Blairmore area, horizontally also. The conglomerate in places is 50 feet above the uppermost coal seam of the underlying Kootenay formation, and in other places it practically forms the roof of the seam."

The Kootenay formation in the Blairmore area is underlain by the Fernie formation. W. W. Leach (1912, p. 194) placed the contact of the Kootenay and Fernie formations on York Creek at the base of greenish thin-bedded sandstone, 75 feet thick, which was stated to lie conformably upon shales of the Fernie. Elsewhere in his report (Op. cit. p. 193), Leach

stated "The line of demarcation between these shales and the overlying Kootenay formation is not very sharply drawn, but may be assumed to be at the base of the lowest heavy bed of sandstone underlying the coal seams." Commenting on the contact B. Rose (1917, p. 109) wrote "There is a gradual change from marine shales to subaerial sandstone, and the line of demarcation used is at the base of the first heavy bed of sandstone." Thus Rose cites a measured section at Blairmore, in which the base of the Kootenay is a massive grey sandstone, 100 feet thick. J. S. Stewart (1919, p. 26) also noted the uncertain character of the basal contact, for he states "the passage of the one formation (Fernie) to the other (Kootenay) is thought to be transitional in character, and the position of the dividing line between them is somewhat indefinite. The base of the Kootenay is usually placed at the horizon where the arenaceous beds and sandstones become predominant, and these strata consist of a series of thin-bedded sandstones and shales of a dark greenish colour, that are rather friable on weathering."

In considering the top beds of the Fernie formation F. H. McLearn (1916, p. 111) wrote as follows: "The uppermost thin-bedded arenaceous member is very characteristic of the Fernie . . . It consists of alternating beds of dark shale and sandstone in 1 to 2-inch layers. The writer has collected a few fish teeth and scales from this zone. The thin bedding persists almost to the thick sandstone at the base of the Kootenay. Within a few feet of it are sandstone beds, 2 feet or more thick, interbedded with thin sandstone and shale. There is thus gradation to the basal sandstone, as noted by Cairnes and others, suggesting continuous deposition." Later McLearn (1929, p. 87) referred to these top beds of the Fernie as "passage beds," assigning them a thickness of about 180 feet. From them he gathered a depauperate and poorly preserved fauna with both marine and non-marine elements. The fauna includes indeterminate pelecypods at Grassy Mountain, shark teeth and fish bones and scales north of the Rocky Mountain sanatorium, and fish fin rays, a fish-like tooth, and a caudal vertebra of an herbivorous dinosaur ? on Castle River."

KOOTENAY AGE LIMIT SET BY FERNIE FORMATION.

The "passage beds" of McLearn at the top of the Fernie formation have not yet furnished fossil evidence indicative of

their age. They are underlain by the "green beds" of McLearn (1929, p. 87), about 50 feet thick, which carry a sparse marine fauna not diagnostic beyond indicating a probable Jurassic age. The latest zone in the Jurassic Fernie formation that could be confidently dated in the Blairmore area was Upper Bathonian or late Middle Jurassic age. (Spath, L. F., 1932, p. 145.) The Kootenay formation, therefore, insofar as its stratigraphic relations to the Fernie are concerned, in the Blairmore area, could be of Upper Jurassic age. On the other hand it is quite possible that a hidden disconformity at the present base of the Kootenay or at some lower horizon, may represent all post-Fernie Jurassic time and an unknown part of Cretaceous time.

KOOTENAY AGE LIMIT AS SET BY BLAIRMORE FORMATION.

Blairmore Floras. The Blairmore formation, which overlies the Kootenay with at least local erosional unconformity, is plant-bearing almost throughout. McLearn made collections of both plants and invertebrate freshwater shells, carefully recording the exact horizons of their occurrence within the formation. (See Figure.) The plants were submitted to, and reported upon, by E. W. Berry (1929, pp. 31-72). They were found to represent two distinct floras within the Blairmore formation, one extending nearly throughout the formation to about 300 feet from its top, the other confined to this latter interval.

The plant-bearing beds with the lower flora begin about 200 feet above the base of the Blairmore formation, and extend upward 1370 feet or 480 feet from the top. This lower flora was considered by Berry to be Late Aptian and Albian (Berry, E. W., 1929, p. 33). The same flora occurs farther north in Alberta in the Luscar and Gething formations. Collections from these formations have greatly enlarged our knowledge of the flora since Berry's analysis of it, and this, together with revision of Berry's identifications, has permitted a new evaluation of the evidence. In the writer's opinion the flora is wholly Aptian, while the succeeding flora, present only in the uppermost 300 feet of the formation, represents early Albian, and, not as Berry considered, Cenomanian time. Evidence for this view will now be considered.

The lower flora present in the Blairmore formation (B)

and in the equivalent Luscar (L) and Gething (G) formations, as at present known, comprises the following species:

L,	*Selaginellites* n. sp.
B, L,	*Equisetum lyelli* Mantell (including forma *burchardti* Schenk, non Dunker).
B, L, G	*Sphenopteris* (*Onychiopsis* ?) *latiloba* Fontaine.
L,	*Sphenopteris* n. sp.
B, L,	*Sphenopteris* (*Onychiopsis* ?) n. sp.
B,	*Sphenopteris* (*Coniopteris* ?) n. sp.
L, G	*Onychiopsis psilotoides* (Stokes and Webb).
B, L, G	*Ruffordia goepperti* (Dunker) Seward.
L,	*Acrostichopteris* n. sp.
L,	(very rare) *Coniopteris heterophylla* (Fontaine) n. comb.
B, L, G	*Coniopteris brevifolia* (Fontaine) n. comb.
L,	*Coniopteris* n. sp. 1.
B, L, G	*Coniopteris* n. sp. 2.
B, L, G	*Coniopteris berryi* nom. nov. for *C. pachyphylla* pars Berry (non Fontaine) Nat. Mus. Can. Bull. 58, pl. 7, figs. 3, 4 (non figs. 1, 2) (1929).
B, L, G	*Cladophlebis virginiensis* Fontaine emend. Berry.
B, L,	*Cladophlebis parva* Fontaine.
B, L,	*Cladophlebis oerstedi* (Heer) Seward.
B, L,	*Cladophlebis* (*Klukia*) *browniana* (Dunker) Seward (includes *C. dunkeri*).
L,	*Gleichenites gieseckiana* (Heer) emend. Seward.
L,	*Gleichenites nordenskioldi* (Heer) emend. Seward.
L,	*Gleichenites* ? n. sp.
B, L,	*Sagenopteris elliptica* Fontaine.
B, L,	*Sagenopteris mclearni* Berry.
B, L, G	*Sagenopteris* n. sp.
G	*Ptilophyllum arcticum* (Goeppert) Seward.
L, G	*Ptilophyllum speciosum* (Heer).
B, L, G	*Ptilophyllum dunkerianum* (Goeppert).
L, G	*Pterophyllum concinnum* Heer.
L, G	*Pterophyllum* n. sp.
B,	*Zamites* sp.
G	*Pseudocycas* n. sp.
B, L, G	*Nilssonia johnstrupi* Heer.
L,	(rare) *Ctenis borealis* (Dawson).
B, L,	*Ctenopsis insignis* Fontaine, omend. Berry.
G	*Ginkgoites lindleyana* (Schimper).
B, L, G	*Ginkgoites pluripartita* (Schimper).
B,	*Ginkgoites browniana* (Dunker).
B, L,	*Phoenicopsis arctica* (Heer).

	G	*Phoenicopsis angustifolia* Heer.
	L, G	*Podozamites lanceolatus* (Lindley and Hutton).
B,		*Nageiopsis* sp. cf. *zamioides* Fontaine.
B,	L, G	*Elatides curvifolia* (Dunker).
B,	L, G	*Elatides dicksoniana* (Heer) n. comb.
B,	L, G	*Athrotaxites ungeri* Halle.
B,	L, G	*Elatocladus* (*Sequoia* ?) *smittiana* (Heer).
	L,	*Elatocladus* (*Sequoia* ?) *rigida* (Heer, pars) Seward.
B,	L, G	*Pityophyllum nordenskioldi* (Heer) n. comb.
	L,	*Pityophyllum* sp. cf. *longifolium* Nathorst.
B,		*Sapindopsis variabilis* Fontaine.
	G	*Carpolithus* (*Nyssa* ?) n. sp.

The above list comprises 49 species, of which 12 are new, as compared with 28 species listed by Berry. The flora may be compared with other Lower Cretaceous floras e.g. (1) the Wealden of England, (2) Kome of Greenland, (3) Potomac of eastern United States.

Wealden elements. There are very few species in this earlier Blairmore flora that occur in the Wealden of England. They comprise only *Equisetum lyelli*, *Onychiopsis psilotoides*, *Ruffordia goepperti*, *Cladophlebis browniana*, *Ptilophyllum dunkerianum* and *Elatides curvifolia*. In addition *Ctenis borealis* may be represented in the Wealden by *Ctenis* sp. Seward (1913, p. 101), while *Pseudocycas* n. sp. is probably closely allied to *P. saportae* (Seward). Except for *Onychiopsis psilotoides* and *Equisetum lyelli* and *Ctenis borealis* this Wealden element of the Blairmore has not yet been found in the underlying flora of the Kootenay formation. Apparently an unknown part of the English Wealden may be of Lower Aptian age, for the highest beds of the Wealden shale have in places a brackish water fauna (J. F. Kirkaldy, 1939, p. 411), and the overlying marine Atherfield clay is late Lower Aptian. The described Wealden flora of England, however, came mostly from the Hastings beds or lower Wealden. These latter rest on Purbeck beds of Jurassic age although "a notable and sudden lithological change again being present" (Boswell, P. G. H., 1929, p. 383). Nevertheless the palaeontological break between the Wealden and Purbeck is generally considered to be slight (*Ibid*, p. 388). So, if the Wealden flora of England were actually earlier than Aptian, and if the age of the lower flora in the Blairmore were judged solely on the basis of its

Wealden element, it might be assigned a pre-Aptian age. opposition to this is the presence in the lower Blairmore f of the dicotyledon, *Sapindopsis variabilis*, and of the pres in an upper part of the formation without any signs of ir vening depositional break, of a flora consisting dominantl angiosperms. This latter flora the writer considers to indi an Albian age, for he agrees with Berry that it is to be cc lated with the flora of the Cheyenne sandstone of Ka (Berry, E. W., 1929, pp. 56, 57). In England dicotyle made an analogous first recorded appearance in very late L Aptian or in early Upper Aptian age in deposits of the L Greensand. A second important newcomer in the lower f of the Blairmore is *Elatocladus* (*Sequoia* ?) *smitti* Although no cones of *Sequoia* have been found associated the foliage, A. C. Seward (1927, p. 103) has noted Flo opinion on the basis of cuticular characters that this sp is more nearly related to *Sequoia* than to any other genus. may be significant that petrified remains of *Sequoia* are pre in the Lower Greensand, although the genus, or a closely a one, apparently appeared as early as the Portlandian of Fra

In summation, the testimony of the Wealden elements in lower flora of the Blairmore is inconclusive, partly bec these elements are very few, and partly because the age li of the Wealden itself is doubtful. On the other hand the presence of dicotyledons, and the presence of a prob *Sequoia* allies the flora to that of known Aptian deposit England.

Kome elements. Many of the more characteristic specie the lower flora of the Blairmore formation are present in Kome beds of western Greenland. Chief of these are: *Sphe teris psilotoides*, *Cladophlebis oerstedi*, *Gleichenites giesecki Gleichenites nordenskioldi*, *Pterophyllum concinnum*, *Ptilop lum arcticum*, *Ptilophyllum speciosum*, *Nilssonia johnst Ginkgoites pluripartita*, *Ginkgoites lindleyan*, *Phoenico arctica*, *Elatocladus* (*Sequoia?*) *smittiana* and *Elatides c soniana*. Some of these species are considered sufficiently d nostic unequivocally to correlate this flora with that of Kome. Unfortunately there is no reliable information on range of these species within the Kome deposits or on the cise age or ages represented by the Kome. Heer himself related the Kome series as Urgonian (Barremian), but

	GREEN BEDS	PASSAGE BEDS (Jurassic)	KOOTENAY F (Neocomian-L or Barr
Sphenopteris (Coniopteris?) n. sp.			
Sphenopteris (Onychiopsis?) n. sp.			
Sphenopteris (Adiantum?) montanense (Know			
Onychiopsis psilotoides (Stokes & W.)			
Ruffordia goepperti (Dunker)			
Acrostichopteris n. sp.			
Coniopteris heterophylla (Font.)			
Coniopteris brevifolia (Font.)			
Coniopteris n. sp. 1			
Coniopteris n. sp. 2			
Coniopteris n. sp. 3			
Cladophlebis virginiensis Font.			
Cladophlebis parva Font.			
Cladophlebis oerstedi (Heer) Seward			
Cladophlebis (Klukia) dunkeri (Schimper)			
Sagenopteris elliptica Font.			
Sagenopteris mclearni Berry			
Sagenopteris n. sp.			
Ptilophyllum arcticum (Goeppert)			
Ptilophyllum dunkerianum (Goeppert)			
Ptilophyllum speciosum (Heer)			
Zamites sp.			
Nilssonia schaumburgensis (Dunk.)			
Nilssonia n. sp.			
Ctenopteris insignis Fontaine			
Ginkgo pluripartita Schimper			
Ginkgo brauniana (Dunker)			
Czekanowskia dichotoma Heer			
Phoenicopsis arctica (Heer)			
Podozamites lanceolatus (L. & H.)			
Nageiopsis cf. zamioides Font.			
Elatides curvifolia (Dunk.)			
Elatides dicksoniana (Heer)			
Athrotaxites ungeri Halle			
Elatocladus (Sequoia?) smittiana (Heer)			
Pityophyllum nordenskioldi (Heer)			
Sapindopsis variabilis Font.			
Sphenopteris foersteri (Debey & Ett.)			
Sphenopteris latiloba Fontaine			
Sapindopsis belviderensis Berry			
Ficus ovatifolia Berry			
Platanus heeri? Lesq.			
Aralia rotundata Dawson			
Cinnamoides ovalis (Dawson)			

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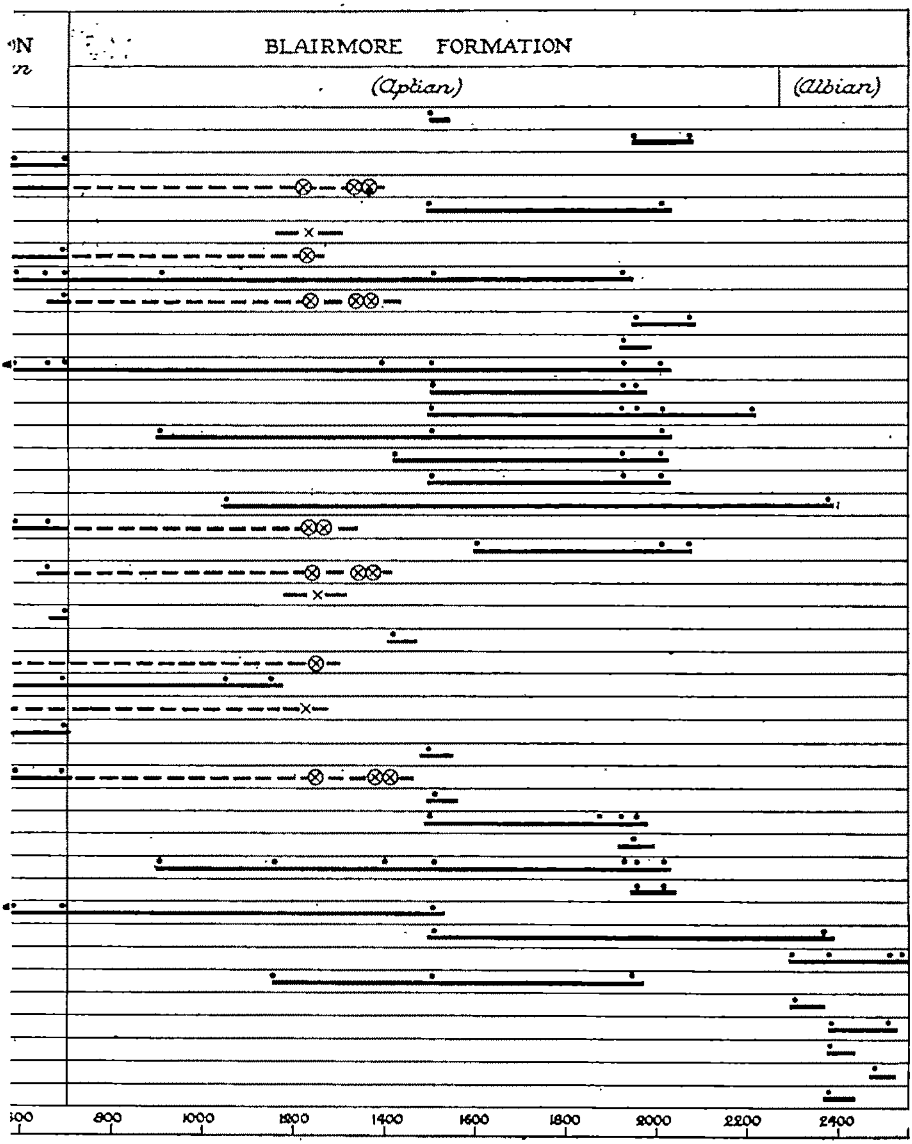
FIGURE SH

Certified ranges in Koote
Horizon of collections
Horizon within Blairn
Horizon within equiva
Horizon within equiva



RATIGRAPHIC RANGES OF SPECIES

LEGEND

Blairmore formations ....

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nation undefined.........................—×—

car formation undefined...........— — — ⊗

king formation undefined........— — — ⊗⊗

significant that a dicotyledon, "*Populus primaeva*" was associated with the typical Kome flora. At Kook (Kome) C. Schuchert and D. White (1898, p. 347) found an additional dicotyledon, viz. *Laurus ?* sp. associated with Kome species, and expressed doubt on the reference of the Kome to as low an age as Urgonian. (op. cit. pp. 347, 366). The Atane flora succeeding that of the Kome has been considered generally to be of Cenomanian age. To the writer Schuchert and White's floral list from their locality C on Pagtorfik (op. cit. p. 353), derived from beds apparently low down in the Atane series, seems rather to indicate an Albian age. At any rate the composition of the two successive floras of the Blairmore formation is closely paralleled by that of the Kome and succeeding early Atane floras. Since *Sapindopsis variabilis* makes its first appearance in the lower flora of the Blairmore, and ranges upward into the succeeding Albian flora, the age of the former like that of the Kome is believed to be younger than Urgonian (Barremian) and to be more probably Aptian.

Potomac elements. The revision of the lower flora of the Blairmore formation reveals that there are few species held in common with the Potomac group. These are: *Sphenopteris* (*Onychiopsis ?*) *latiloba*, *Onychiopsis psilotoides*, *Coniopteris brevifolia*, *Cladophlebis virginiensis Cladophlebis parva*, *Cladophlebis browniana*, *Sagenopteris elliptica*, *Ctenopsis insignis*, *Podozamites lanceolatus* and *Sapindopsis variabilis*. In addition, *Sphenopteris* (*Onychiopsis ?*) n. sp. is seemingly closely allied to *Thinnfeldia marylandica* Fontaine, *Acrostichopteris* n. sp. to *Baieropsis foliosa* Fontaine, and *Nageiopsis* cf. *N. zamioides* to *N. zamioides* Fontaine. On the basis of these few species alone no satisfactory correlation of the lower part of the Blairmore in terms of the Potomac may be made. Yet the flora of the upper part of the Blairmore which carries *Menispermites potomacensis*, *Celastrophyllum acutidens ?*, *Sapindopsis variabilis*, and *Araliaephyllum*, may with some confidence be correlated with that of the Patapsco formation. The appearance of dicotyledons in the earlier Blairmore flora certainly seems to link this closer to that of the Patapsco than to that of the earlier Patuxent-Arundel flora, and indicates that its chronological position may be represented by the hiatus that has been placed between the lower Potomac and Patapsco formation.

Conclusion. The lower flora of the Blairmore formation has closer affinities with the Kome flora than of any other described flora of Lower Cretaceous age. The flora is most probably Aptian in age because: (1) within it is the first appearance of unquestionable dicotyledons, of which one species at least, *Sapindopsis variabilis* ranges upward into the Albian flora of the upper part of the Blairmore formation; (2) there is no discernible break in sedimentation or lithology within the two hundred foot interval separating the two Blairmore floras; (3) common first appearance of *Sequoia* or of a closely allied genus in the flora; (4) the mixed flora of cycadeoids and angiosperms has an analogy in the petrified flora of the Lower Greensand (Aptian) of England. In support of an Aptian age is the affinity existing between the lower Blairmore flora and an Aptian flora from the Lago San Martin area, Patagonia, described by T. G. Halle (1913). The species common to the two floras are *Ruffordia goepperti*, *Sphenopteris psilotoides*, and *Athrotaxites ungeri*. The last mentioned is of most significance since its identification is based on fertile as well as upon sterile remains. Other elements in the Patagonian flora closely allied to some in the Blairmore flora are *Cladophlebis* cf. *browniana*, and *Sphenopteris* cf. *naktongensis* Yabe (perhaps con-specific with *Sphenopteris latiloba*). Moreover, fragments doubtfully referred to dicotyledons are present. The Aptian age of the Patagonian flora is in accord with ammonite evidence from associated beds, some of which apparently underlie the plant-bearing deposits.

Since the upper age limit of the Kootenay flora as set by the earliest Blairmore flora is probably Aptian, and since the lower age limit as set by the marine Fernie formation is early Upper Jurassic, either a late Jurassic or Neocomian-Barremian age for the Kootenay is possible. Which of these is the more probable must be decided from the evidence of the Kootenay flora itself.

THE KOOTENAY FLORA.

A revision of the Kootenay flora present in the Blairmore area reduces the known species to fifteen. All but three of these were collected from beds lying within the upper half of the formation. The first and most notable feature of the flora is its almost entire lack of individuality, for of the 15 species present in the Kootenay only 3 are confined to that formation.

The remainder (see Figure) are all present in the younger Blairmore or equivalent Luscar and Gething formations. This range of species certainly does not suggest the presence of any time-break in sedimentation sufficient to embrace all Neocomian-Barremian time. On the contrary a late Neocomian (Infra Valenginian to Hauterivian inclusively) or early Barremian age for the upper part of the Kootenay in its type area is more probable.

The three species that are so far as known confined to the Kootenay are: *Sphenopteris* (*Adiantum* ?) *montanense*, *Nilssonia schaumburgensis* and *Czekanowskia dichotoma*. The first of these is a form-genus by no means well characterised specifically. Similar forms are represented by *Adiantum formosum* Heer (name preoccupied) from the Kome of Greenland, and by *Adiantum expansum* from Albian beds of Portugal. Hence the Kootenay species does not suggest a Jurassic age. *Nilssonia schaumburgensis* shows transitions from typical narrow forms of the species to forms approaching *Nilssonia californica* Fontaine, which are more common in Jurassic floras, but also present in formations of Alberta younger than the Kootenay. The typical forms of the species are characteristic of the Wealden and other Lower Cretaceous deposits. *Czekanowskia dichotoma* is about the only species present in the Kootenay that strongly suggests a Jurassic age. Even the genus is essentially Jurassic, and *Czekanowskia dichotoma* is apparently closely allied to, if not actually conspecific with the Jurassic *Czekanowskia rigida*. Yet the presence of *Czekanowskia dichotoma* in the Kome of Greenland, in deposits inferred by the writer to be younger than the Kootenay, was reported by Heer and confirmed by White and Schuchert. Another Jurassic "holdover," *Podozamites lanceolatus*, occurring in the Kootenay, ranges upward into the Blairmore formations and its equivalents. *Ctenis albertensis* Warren (=*Ctenis borealis* Dawson), claimed by Warren (Warren, P. S. 1927) to indicate a possible Jurassic age, occurs also, although rarely, in the Luscar formation. Indeed it is a surprising fact that the younger, presumably Aptian flora of the Blairmore, Luscar and Gething formations contains more of the characteristically Jurassic genera, e. g. *Sagenopteris*, *Zamites*, *Nilssonia* of the *orientalis* group, *Phoenicopsis*, and *Elatides*, than does the older flora of the Kootenay. This younger flora is almost as well differentiated from the Kootenay flora by the very pres-

ence of these "Jurassic elements" as by the entrance of new species. It is meaningless, therefore, to speak of "the Jurassic aspect" of the Kootenay flora in exclusion of the Blairmore flora.

In any chronological evaluation of a flora it is the entrance of new species that has significance. The flora of the Kootenay has so far provided too few species to permit dogmatic judgment as to its age, but the writer considers that the entrance within it of *Coniopteris heterophylla*, *Onychiopsis psilotoides*, *Ptilophyllum arcticum*, and *Ptilophyllum speciosum* weighs heavily in favour of a Lower Cretaceous age. The further fact that nearly all the species present in the Kootenay are likewise present in the younger flora of the Blairmore or equivalent formations, again lends strong support to a Cretaceous age. Whether the age of the Kootenay is Neocomian or Barremian or some part of both cannot as yet be satisfactorily determined by an analysis of the flora. In the Blairmore area the erosional unconformity at the base of the Blairmore formation is crossed by the ranges of a sufficient number of species to lead the writer to infer that the time-break, in that area at least, is only minor, and that the upper part of the Kootenay is there more probably Barremian or late Neocomian than Early-Neocomian (Infra Valanginian-Valanginian).

Beyond the Blairmore area little is known about the location of plant-bearing horizons within the Kootenay or in equivalent formations. A topmost part of the Nikanassin formation has supplied in places a few plants that are believed to indicate an age equivalent to an upper part of the Kootenay. Thus, from one locality in the Brule coalfield, 65 feet below the Cadomin conglomerate, a few plants were collected by B. R. McKay of the Geological Survey, Canada. They include *Equisetites lyelli* forma *burchardti*, *Onychiopsis psilotoides*, *Coniopteris* n. sp. 1, and *Czekanowskia dichotoma*. But from another locality, on North Hay River, the Nikanassin furnished *Nilssonia nigracollensis* and *Laccopteris* n. sp. Whether these two species indicate an earlier Lower Cretaceous or even an Upper Jurassic age for a lower part of the Nikanassin formation cannot be judged until more plant collections from accurately located horizons are forthcoming.

The plants from the Kootenai of Montana, to judge from published accounts, have added little to our knowledge of the flora of the Canadian Kootenay. From the time Canadian

geologists clearly differentiated the Blairmore and Kootenay formations (McLearn, F. H. 1916, 1929; Rose, B. 1917; Berry, E. W. 1929) it was evident that the Kootenai of Montana embraced parts of both the Kootenay and Blairmore formations of Alberta. Of the floral lists from five horizons in the lower Kootenai presented by Fisher (Fisher, C. A. 1908, pp. 33, 34) the two stratigraphically lowest could confidently be considered as the age of the Canadian Kootenay, while the remaining florules from 150 feet and more above the base of the formation could be assigned to the early flora of the Blairmore. The florule described by Newberry (1891, pp. 191-201) seemed to belong to the early Blairmore flora, whereas that described by Fontaine (in Ward, L. F. 1905, pp. 284-315) was apparently Kootenay. R. W. Brown (1946, pp. 241-244) has recently discussed the Kootenay species present in the basal part of the Montana Kootenai. It may be hoped that we will eventually be given the range of the species comprising the two or more floras in the Kootenai group of Montana.

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SCIENTIFIC INTELLIGENCE

Physics and Chemistry.

The A Priori in Physical Theory; by Arthur Pap. 112 pages. New York. 1946 (King's Crown Press, $2.00).—Most of the modern philosophy of physical science is concerned with the nature and sources of concepts and principles (laws). Ever since he proposed them in the eighteenth century, Kant's constitutive elements of experience have been the basis of much of the epistemology of philosophical scientists. The most troublesome element to modern physicists has, historically, been Kant's acceptance of synthetic *a priori* truths as the basis of "natural" science, as for example, the axioms of Euclidean geometry (which Kant considered as "natural"). Interpretations of this have been proposed by Poincare, Lenzen, and others among scientists, and by Cassirer among philosophers; under the guidance of these men, Doctor Pap has considered the rôle of the *a priori* in physical theory. Based to a great extent on Poincare's *conventionalism* and Lenzen's idea of *successive redefinition,* he has developed a functional interpretation: ". . . we accept Kant's doctrine of 'synthetic a priori' principles only insofar as 'synthetic a priori' is predicated of *regulative* principles of science, not insofar as it is predicated of ultimate and unchanging constitutive conditions of experience (which) are rooted in the very nature of human understanding and intuition." For him, a proposition is *a priori* only in a context; what is *a posteriori* in one situation may become *a priori* in another. By "constitutive elements," Pap would understand definitions and principles which have been transformed from induced generalizations; indeed that which is known as scientific truth develops from the initial status of *synthetic* empirical conclusions to that of *analytic* necessity, in terms of which further investigation is defined. In this genetic process, "the scientist's ways of conceiving his entities undergo, under the pressure of discovery, a constant change."

The reactions of avowed Kantians to this dynamic "functional" application of the synthetic *a priori* will probably not differ greatly from their reactions to the original conventionalism of Poincare. The book represents Pap's Ph.D. dissertation at Columbia University. It should be of interest to scientists concerned with physical methodology. ROBERT S. COHEN.

Surface Active Agents; by M. L. Anson, R. R. Ackley, E. K. Fischer, D. M. Gans, M. H. Hassialis, R. D. Hotchkiss, D. Price, A. W. Ralston, L. Shedlovsky, and E. I. Valko, Volume

XLVI, Article 6, pp. 847-580, Annals of The New York Academy of Sciences, New York, 1946 (The New York Academy of Sciences, $2.25)—This monograph contains a series of papers which were presented at a conference on surface active agents held by the Section of Physics and Chemistry of The New York Academy of Sciences in January 1945. The scope of the monograph may be judged from a brief description of each paper. Introduction (Anson); "The structure and properties of solutions of colloidal electrolytes" (Ralston) deals chiefly with the soaps; "Surface active agents at interfaces" (Fischer & Gans) reviews the properties measured at various interfaces by a number of experimental methods, the factors which affect the validity of such measurements, and the industrial processes and products which may be understood in the light of these quantitative measurements; "Certain aspects of the chemistry of surface active agents" (Price) attempts to correlate constitution with performance of surface active agents; "Properties involving surface activity of solutions of paraffin chain salts" (Shedlovsky) is a discussion of careful experimental work on the properties exhibited by a series of very pure substances when subjected to tests for surface activity; "Surface active agents in biology and medicine" (Valko) reviews the combination of surface active ions with proteins, the denaturation, precipitation and dissolving of proteins by surface active ions, and the action on enzymes, viruses, and bacteria; "The nature of the bactericidal action of surface active agents" (Hotchkiss) is described by its title; "Surface active compounds in flotation ore dressing" (Hassialis) discusses collecting, frothing and attachment agents and other related aspects of flotation; "The industrial use of surface active agents" (Ackley) discusses some of the problems of predicting and evaluating surface active agents.

The papers are well written and thoroughly documented. Almost every paper is followed by some discussion. There are many illustrations. This monograph seems to the Reviewer to be an important addition to the literature on surface active agents.

HAROLD G. CASSIDY.

Organic Reagents for Organic Analysis; by STAFF OF HOPKINS AND WILLIAMS RESEARCH LABORATORY. Pp. 175. Brooklyn 1946 (Chemical Publishing Co., Inc., $3.75).—In this book, the scope of which as stated in the Preface is "the use of organic reagents in preparing derivatives of organic substances for purposes of identification by melting points," the authors, W. C. Johnson, R. J. Shennan, and R. A. Reed, have done a very useful piece of work. Apart from the fact that the Authors bring together in one place information which otherwise would have to be sought out through

many sources, and so for this alone earn our thanks, they have done a more useful thing: they have at the same time sorted and criticized.

The book is divided into five sections. The first is Chemical Groups and Their Derivatives. Here the types of compounds to be identified are listed alphabetically, and under each type (say aldehydes and ketones, as an extreme example) there are listed "Selected Reagents" (10 in this case) and "Other Reagents" (some 53). The selected reagents are discussed briefly. Their choice is based upon practical considerations: accessibility of the reagent (reasonable price); stability of reagent; simplicity, convenience and speed with which derivatives can be prepared; that the melting point of the derivative falls within a convenient range; that the derivatives allow differentiation of closely related compounds; that at least to some extent the reagent has been tested with a large number of compounds of the given type; that the derivative provides a reactive group which may then be titrated for additional characterization. The other reagents are listed, often with some explanation of why they are not selected, and in each case with literature references. For example, under Alkaloids, "the Other Reagent" is picrolonic acid, which is not a selected reagent because "The picrolonates of the alkaloids are unsatisfactory derivatives, since their melting points lie very close together and melting is accompanied by decomposition" (p. 18). Many examples could be given of the valuable critical information which is contained in this section.

In the second section, on Selected Reagents, each reagent is described, the compounds for which it is a reagent are listed, and the method of its use is described. Here also critical comments of a most useful nature are made. Equations for the reactions which lead to derivatives are given. The third section is composed of Melting Point Tables. These are arranged alphabetically throughout, and each table has one or more columns headed by the names of the reagents used to give the derivatives the melting points of which are listed. Thus Amides has one column, the only derivatives listed being prepared with xanthydrol, while Phenols has 18 columns. A good feature of this section is that melting points which have been confirmed in the laboratories of Hopkins and Williams are printed in heavy type, and those which are for new compounds, or which are somewhat different from those given in the literature but which have been obtained on substances of known purity are printed in italics. The fourth section is an alphabetical summary of the selected reagents. The fifth is a General Index which covers the reagents and types of compounds, but not derivatives.

This book will be found very useful by all organic chemists who have to characterize compounds. It will be a handy reference for

courses in qualitative organic analysis. It would be useful also in the case of quantitative organic analysis, since where these reagents have quantitative applications, these have been pointed out. The book is well put together and presents a pleasing appearance.

HAROLD G. CASSIDY.

Photosynthesis and Related Processes. Volume I. *Chemistry of Photosynthesis, Chemosynthesis and Related Processes in Vitro and in Vivo.* EUGENE I. RABINOVITCH, Research Associate, Solar Energy Conversion Research Project. Massachusetts Institute of Technology. Pp. xiv, 614; 68 figs. New York, 1945 (Interscience Pub., Inc., $8.50).—Twenty years have passed since the publication of Spoehr's well-known monograph on Photosynthesis. During these years a bewildering number of papers have appeared in an equally bewildering number of different journals which bear upon this most important of all biochemical reactions. Biologists, chemists and physicists owe a great debt of gratitude to Doctor Rabinovitch for having furnished them with this impatiently awaited, competent and critical handbook to guide them through the veritable jungle of information on this important subject. Students, teachers and investigators who are genuinely interested in the fascinating problem of photosynthesis will find this admirable book indispensable. It not only presents in a lucid manner the present status of the problem and the thoughts which have led up to it, but also abounds in ideas which should stimulate further research.

The present volume is the first of a series of two to be devoted exclusively to the problem of photosynthesis and related subjects. It is subdivided into two significant parts: I, The Chemistry of Photosynthesis and Related Processes (815 pp.), and II, The Structure and Chemistry of the Photosynthetic Apparatus (820 pp.). A second volume, dealing principally with the physical and physicochemical aspects of the problem, such as the spectroscopy and fluorescence of pigments, and the kinetics of photosynthesis is to be published in the near future.

The introduction to the present volume comprises two chapters dealing with the rôle of photosynthesis in nature and the discovery of the phenomenon. The latter chapter may well serve as a model for an intelligent review of scientific historical background on a minimum number of pages. The first principal part of the book begins with chapters on the over-all reaction and the products of photosynthesis and on photosynthesis and related processes outside the living cell. They are followed by chapters dealing with the photosynthesis and chemosynthesis of bacteria and the metabolism of anaerobically adopted algae. The next chapter presents an intelligent critical discussion of the present concepts of the primary

photochemical process. The remainder of the first part is taken up by four chapters on nonphotochemical reactions, such as the fixation of carbon dioxide and the liberation of oxygen, and two chapters on the inhibition and stimulation of photosynthesis by various physical and chemical agents. The six chapters of the second part of the present volume are devoted entirely to a discussion of the chloro- and chromoplasts, the pigment systems, chlorophyll and accessory pigments, and their photochemistry *in vivo* and *in vitro*. The author has wisely refrained from discussing the complex organic chemistry of the various pigments beyond their relationship to the mechanism of photosynthesis. To the end of each chapter has been attached a carefully selected bibliography of pertinent articles, arranged in chronological order. WERNER BERGMANN.

Encyclopedia of Chemical Reactions, Vol. I. Compiled and Edited by C. A. JACOBSON. New York, 1946 (Reinhold Publishing Corp., $10.00).—The first volume of the Encyclopedia of Chemical Reactions contains the reactions of aluminum, antimony, arsenic, barium, beryllium, bismuth, boron, and bromine. The reactions are arranged alphabetically first according to the formulas of the reactants and then according to the reagents. Each entry is given a serial number indicating the volume number and the position of the entry in the volume. A brief statement of the conditions of the reaction is followed by one or more equations. The abstract is completed by the inclusion of a reference to the original publication and an occasional second reference. The abstractor can be identified by a number below the serial number of each reaction referring to a list of the names and addresses of the abstractors given at the end of the book.

Altogether, there are three thousand and seventy-three reactions contained in this first volume of the series. These are classified according to the reagents in one index and according to the products in a second index which in turn is divided into one section of names and another of formulas.

Considering the magnitude of the task, the book is remarkably free from typographical errors. One such error is to be noted in entry 287 where $AlCl_2^+$ is written as $AlCl_3^+$ and another in entry 1115 where $AsBr_3$ is written as $AgBr_3$.

The encyclopedia should prove to be valuable indeed to anyone concerned with reactions of inorganic compounds. It is hoped that the remaining volumes will be equally well done. H. M. CLARK.

Fluorochemistry; by JACK DE MENT. Pp. xvii, 796; 80 figs., Brooklyn, N. Y., 1945 (The Chemical Pub. Co., $14.50).—In "Fluorochemistry," the author attempts to give an orderly presenta-

tion of the theory and applications of luminescence. As a result, the book contains a comprehensive treatment of the work of numerous investigators plus a considerable amount of the author's work. In fact, the author is not very subtle about finding innumerable ways of mentioning his own work. Moreover, little, if anything, is added to the understanding of the phenomena of luminescence by shielding Stokes's law between DeMent's so-called first law and third law of fluorescence.

The book is divided into five parts. Part I, "Fluorochemistry in Theory," deals with the physical and physicochemical aspects of luminescence. Part II, "Homogeneous Luminescent Systems," covers organic substances and dyestuffs. Part III, "Heterogeneous Luminescent Systems," is a general treatment of phosphors including directions for the preparation of synthetic phosphors. Part IV, "Ultraluminescence and Infraluminescence," is concerned mainly with substances which emit ultraviolet and infrared radiation. Part V, "Fluorochemistry and Fluorobiology," relates luminescence to biological studies.

There are several useful tables of properties of luminescent substances in the book. One such table contains a list of two thousand eight hundred and ninety-six organic compounds with individual notations about excitation conditions, nature of the luminescence produced, solvent, and literature references.

A table of nomenclature of fluorochemistry and a bibliography are included in the appendices. Extensive references are given at the end of each of the five parts of the book.

Some of the illustrations are rather crudely drawn and although the sections dealing with the theoretical aspects of luminescence cover a wide variety of topics, they are rather qualitative in nature.

The active worker in the field of luminescence should find that the tables and literature survey make "Fluorochemistry" a useful book.

H. M. CLARK.

Physical Chemistry for Premedical Students; by JOHN PAGE AMSDEN. International Chemical Series. Pp. ix, 298; 54 figs. New York, 1946 (McGraw-Hill Book Co., Inc., $8.50).—This book is designed for the general premedical student, not the one who intends to do research in biological fields, but the run-of-the-mill student who apparently has time for only one semester of physical chemistry and whose mathematical training is limited to elementary algebra with perhaps a smattering of calculus. Such a short course requires that only "those phases of the subject that appear to be of value to the general medical student" be included. Teachers will welcome the worthwhile features of this book: the large number of lecture demonstrations which are described in the text, the note-

worthy list of motion pictures and film strips in an appendix, and the numerous illustrations drawn from biology or medicine. The importance of being able to solve problems is recognized, and a good many problems have been worked out in the text. But the attempt "to devise problems that are not merely mathematical exercises but involve some reasoning on the part of the student" has not been particularly successful, especially in the first few chapters.

The principal objections to the book stem from its point of view, one more frequently encountered in elementary than in physical chemistry. (As a matter of fact, chapters such as those on Gases and Chemical Equilibrium go no more deeply than the discussions in a good, modern general chemistry textbook.) It is common in teaching elementary chemistry to encourage the use of mental pictures. This valuable method—used frequently by the reviewer himself—brings home to a beginning student the implications of theories. But the teacher must beware, for this approach conceals a pitfall: the mental picture may be so grossly oversimplified that the student will draw erroneous conclusions from it. Unfortunately, this pitfall is not altogether avoided by the author. For example, in his discussion of deviations from Boyle's law the author asserts (p. 26) that as the pressure on a gas is increased "eventually a point is reached where the molecules cannot be brought closer together. At this point, V remains constant as p increases, and $pV > NRT$." Or most students will undoubtedly conclude from simple interpretation of Raoult's law on pp. 75-7 that only non-volatile solutes lower the vapor pressure of the solvent and that Raoult's law holds even in concentrated solutions.

One may question whether frequent over-simplification will really "enable the student to read, understand, and apply much of the work that is being reported in the current literature and to have a better comprehension of the reactions taking place in the human body." The reviewer suggests that the necessary perspective would be supplied by acquainting the student with the methods of thermodynamics. Some will doubtless object that there is no time for such a difficult approach. Is not time better spent on fundamentals? Indeed, the reviewer feels that a more basic approach would save time. The tortuous derivations and devious arguments of, for example, the discussion of the hydrogen electrode can be avoided by use of thermodynamics.

Apart from this objection to the basic point of view, attention should be called to a considerable number of ambiguous and incorrect statements. Space permits but one example: the discussion of the hydrolysis of ammonium cyanide rests upon the unfounded assumption that the ammonium and cyanide ions hydrolyze to the

same extent. Such errors detract from the value of a book which already suffers from an over-simplified approach. E. J. KING.

Introductory College Chemistry; by HARRY N. HOMES. Pp. viii, 590; 168 figs. New York, 1946 (The Macmillan Company, $3.75). —This new edition of a popular textbook preserves the essential features of the third edition (AMER. JOUR. SCI., 338, 69 (1940)) with some improvements. It is designed more specifically for the student without previous preparation in chemistry. The long chapters of the other edition on oxygen, states of matter, and solutions have each been divided in two and a new chapter covering oxides of nitrogen and nitric acid replaces two chapters of the previous book. Although rewriting has not been extensive, there has been considerable interpolation of new material, particularly topics of current interest. The chapters on organic chemistry, which formerly came after the discussion of the phosphorus group, have been moved to the end of the book. Because of this shift the chemistry of the metals can be taken up earlier than before, an advantageous feature if the laboratory work is in qualitative analysis. The seven chapters on compounds of the metals are much the same as before except that more extensive use is made of tables and that the metallurgy and properties of the metals have been extracted and formed into five new chapters. Because of this rearrangement it is possible to stress more effectively group preparations and properties. Much new material has been included in the section on organic chemistry. In its general appearance the book is more pleasing than the previous edition. The rearrangement of topics should enhance the value of this book for teachers who have used the previous edition.

E. J. KING.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Marine Microbiology. A Monograph on Hydrobacteriology; by CLAUDE E. ZOBELL, Foreword by SELMAN A. WAKSMAN. XV. Pp. 1-240; 12 figs. and decorative vignettes by ALMA B. CARLIN. Waltham, Mass., 1946 (The Chronica Botanica Co., $5.00), New York City (G. E. Stechert & Co.)—The bacteriology of the sea is of peculiar interest to oceanographers, biologists, geochemists, sedimentary petrologists, and petroleum geologists as well as to those concerned within any practical marine problems. All such workers owe a debt of gratitude to Doctor ZoBell for the labor involved in the preparation of this monographic study. The material covered is extensive and of somewhat wider interest even than the title suggests. After introductory chapters on the history of the subject and the nature of the marine environment, appropriate techniques

are considered. Then the study of the factors influencing abundance and distribution of bacteria and their characteristics and activities in both the free water and the sediments are taken up. A chapter is devoted to aquatic yeasts and molds. Four chapters on the bacterial transformations of important groups of compounds follow, then a chapter on the relationship of bacteria to the other components of the marine biota, one on the bacteriology of marine air and two on sanitary and other economic aspects. A final chapter is devoted to the bacteriology of inland waters. The bibliography comprises over six hundred references.

Though written largely as a summary of the literature with few synthetic paragraphs, the peculiar nature and importance of the bacteriology of the ocean is easily grasped from a study of this book. Bacteria, though of immense importance in the ocean, do not find in it an ideal habitat. Much of the bacterial flora is concentrated in the upper part of the sediments, or on the surfaces of suspended or sedimenting solid bodies. The open ocean is too low in inorganic compounds to permit vigorous development of a bacterial flora save where adsorption on solid particles concentrates the organic matter. An antibiotic material is, moreover, rather widespread in natural sea water, though the nature of this substance, which may be of great importance in marine biology, is not adequately understood. The specificity of the marine flora is such that marine bacteria can easily be identified in air masses moving onto land from the surface of the ocean. The geologist will find ZoBell's discussion of the lower limit of the biosphere of peculiar interest. Bacteria can be recovered in small numbers from the lower parts of the longest deep sea cores yet taken. The habitat of these bacteria is sediment formed at a quite remote time, in some cases probably during the Pleistocene. There is evidently here a wide and relatively unexplored field of study. ZoBell tentatively suggests that rising earth temperature with increasing depth puts a limit on the survival of bacteria buried in marine sediments.

Marine Microbiology should be carefully studied by everyone interested in any of the many aspects of science on which its subject matter impinges. The book is attractively produced and very well indexed. A few minor misprints were noted but none appear to disguise the author's meaning. G. E. HUTCHINSON.

PUBLICATIONS RECENTLY RECEIVED

Illinois Geological Survey. Report of Investigations as follows: No. 111. Viscosity Studies of System $CaO\text{-}MgO\text{-}Al_2O_3\text{-}SiO_2$: 1, 40% SiO_2; J. S. Machin and D. L. Hanna. No. 12. Rosiclare-Fredonia Contact in and Adjacent to Hardin and Pops Counties, Illinois; by F. E. Tippie. No. 113. Kinkaid Corals from Illinois and Amplexoid Corals from the Chester of Illinois and Arkansas; by W. H. Easton. No. 114. Marine Pool, Madi-

son County. A new Type of Oil Reservoir in Illinois; by H. A. Lowenstam and E. P. Du Bois. No. 115. Diagnostic Criteria for Clay Minerals; by W. F. Bradley. Urbana, 1945 and 1946.

Journal of Polymer Science

Editorial Board—P. M. Doty, R. Houwink, H. Mark, C. C. Price.

Volume I, issues 1 and a 7¼ x 10¼. 147 pages.

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The new journal is devoted to the advancement of our fundamental knowlledge of the physics and chemistry of polymers, by offering to scientific workers in this field an opportunity to report experimental and theoretical contributions through a centralized medium.

Luther Burbank. A Victim of Hero Worship; by W. L. Howard, Waltham, Mass., 1945-1946 (The Chronica Botanica Co., $3.75); New York City (G. E. Stechert and Co.).

Statistical Thermodynamics; by E. Schrödinger. New York, 1946 (Cambridge University Press, The Macmillan Co., $1.50).

Mathematician's Delight; by W. W. Sawyer, New York, 1946 (Penguin Books, Inc., $.25).

Dating the Past, An Introduction to Geochronology; by F. S. Zeuner, London, 1946 (Methuen & Co., Ltd., 30s.).

Modern Chemistry. Some Sketches of Its Historical Development; by A. J. Berry, New York, 1946 (Cambridge University Press) (The Macmillan Co., $2.50).

Physical Methods of Organic Chemistry. Vol. II, Edited by A. Weissberger, New York, 1946 (Interscience Pub. Inc., $8.50).

Advances in Colloid Science. Vol. II. Scientific Progress in the Field of Rubber and Synthetic Elastomers; edited by H. Mark and G. S. Whitby. New York, 1946 (Interscience Pub. Inc., $7.00).

A New Series on Plant Science Books; edited by F. Verdoorn. Vol. XVII. Marine Microbiology. A Monograph on Hydrobacteriology; by C. E. ZoBell, Waltham, Mass., 1946 (The Chronica Botanica Co., $5.00) New York City (G. E. Stechert & Co.).

Principles of Physics II. Electricity and Magnetism; by F. W. Sears. Cambridge, Mass., 1946 (Addison-Wesley Press $5.00).

Principles of Industrial Process Control; by D. P. Eckman. New York, 1945 (John Wiley & Sons, $3.50).

U. S. Geological Survey; 54 Topographic Maps.

The Naturalists' Directory, Salem, Mass., $3.00 postpaid. Contains names, addresses and special subjects of study of professional and amateur naturalists throughout the world. Published regularly for 60 years. Current edition to be issued September, 1946.

Textbook of Biochemistry; by P. H. Mitchell. New York, 1946 (The McGraw-Hill Book Co., $5.00).

Meteorology with Marine Applications; by W. L. Donn. New York, 1946 (The McGraw-Hill Book Co., $4.50).

Kansas Geological Survey. Bulletin 64, Part 1, Petrographic Comparison of Pliocene and Pleistocene Volcanic Ash from Western Kansas; by A. Swineford and J. C. Frye; Preliminary Cross Section No. 2 of Oil and Gas Investigations. Subsurface Geologic Cross Section from Ness County, Kansas to Lincoln County, Colorado; by J. C. Maher, Lawrence, 1946.

American Journal of Science

AUGUST 1946

REVISION OF SOME LATE UPPER CAMBRIAN TRILOBITES FROM NEW YORK, VERMONT AND QUEBEC.

FRANCO RASETTI.

ABSTRACT. A more complete description of species of *Idiomesus, Keithiella, Prosaukia, Raymondina,* and *Westonaspis* is given on the basis of material collected by the writer. New generic assignments are suggested for some of the species, and the genera *Stenosaukia* and *Stigmametopus* are suppressed as respectively synonymous of *Prosaukia* and *Idiomesus.*

THIS study includes species from the Hoyt limestone of New York, the Gorge formation of northwestern Vermont, and the late Upper Cambrian boulders (*Hungaia magnifica* zone) in the Lévis shale of Quebec.

Many Cambrian trilobites have been described from fragments that often did not show enough diagnostic characters for the safe foundation of a species or a genus; and, moreover, in many cases the different parts of the carapace have been assigned to one species upon insufficient evidence. New collecting in the Cambrian formations, especially when done by a paleontologist who is careful of noting the association of the fossils in the rock, almost invariably yields valuable material for a better understanding of these fossils.

Material collected by the writer from the Hoyt limestone and from the Gorge formation affords the means for more complete descriptions, the correct assignment of the different parts of the carapace, and new generic references of several late Upper Cambrian trilobites.

The results of this study confirm the approximate equivalence of the Hoyt limestone, the Gorge formation and the *Hungaia* zone in the Lévis conglomerate. One of the common characteristic genera is *Keithiella,* represented in these formations by closely related species.

SYSTEMATIC DESCRIPTIONS.

Genus IDIOMESUS Raymond, 1924.

The genus is based on *Idiomesus tantillus* Raymond, a species from the Gorge formation. Raymond's description of the genotype is correct except in one detail. Raymond stated that the glabella is unfurrowed, but examination of the type shows that the posterior portion of the glabella is imperfectly preserved in this specimen. Better preserved cranidia show a narrow, but rather deep posterior glabellar furrow crossing the entire width of the glabella.

The writer erected the genus *Stigmametopus* for a trilobite from the Lévis conglomerate which is similar to *Idiomesus tantillus* in most respects. Believing that *Idiomesus* had no glabellar furrows, the writer made a new genus for this species, which shows a deep posterior transglabellar furrow, in addition to two other pairs of short furrows. Now that *Idiomesus tantillus* is better known, the differences between the two species clearly do not justify a generic separation; hence *Stigmametopus* is suppressed as a synonym of *Idiomesus*.

IDIOMESUS TANTILLUS Raymond.

Plate 1, Figs. 1-3.

Idiomesus tantillus Raymond, 1924, Boston Soc. Nat. Hist. Proc., vol. 37, no. 4, p. 397, pl. 12, fig. 10.

Several cranidia of this species were collected by the writer from the type locality. All of them show the well-impressed posterior glabellar furrow that is imperfectly preserved in Raymond's type.

A character of this species that is not mentioned in Raymond's description is the unusual elevation of the very narrow occipital segment and of the posterior rim of the fixed cheeks. A peculiar feature is the fact that the dorsal furrows hardly interrupt this elevated posterior border of the cranidium, although they are unusually deep along the posterior portion of the glabella.

Free cheeks were certainly present, although probably narrow and marginal. There is no trace of palpebral lobes, hence this trilobite seems to have been blind.

The photographs of an almost perfect cranidium clearly show all the above-mentioned features.

Formation and locality: Gorge formation (upper zone); Highgate Falls, Vermont.

Holotype: Yale Peabody Museum no. 4726; plesiotypes: Laval Univ. nos. 1042 a-b.

IDIOMESUS LEVISENSIS (Rasetti).

Stigmametopus levisensis Rasetti, 1944, Jour. Paleont., vol. 18, p. 257, pl. 37, figs. 8, 9.

The presence of two pit-like pairs of glabellar furrows in addition to the posterior transglabellar furrow readily distinguishes this species from *I. tantillus*.

Formation and locality: Upper Cambrian boulders (*Hungaia* zone) in the Lévis formation at Lévis, Quebec.

Syntypes: Laval Univ. nos. 1126 a-b.

Genus KEITHIELLA Rasetti, 1944.

KEITHIELLA SPECIOSA (Walcott).

Plate 1, Figs. 4-9.

Ptychaspis speciosus Walcott, 1879, New York State Mus. Nat. Hist., 32nd Ann. Rept., p. 131.

Ptychaspis speciosus Walcott (part), 1912, Smithsonian Misc. Coll., vol. 57, no. 9, p. 272, pl. 43, figs. 16, 16a, 17, 19.

Saukia speciosa (Walcott), Resser, 1942, Smithsonian Misc. Coll., vol. 101, no. 15, p. 49.

Walcott described this species as *Ptychaspis*, assigning the wrong pygidium to it. Later Resser eliminated the spurious parts of the carapace and, on the basis of the cranidium, assigned the species to *Saukia*. Even a cursory examination of the cranidium suffices to show that the species cannot be assigned to any of the genera of the Saukiinae as defined by Ulrich and Resser. The palpebral lobes are much shorter than in any of the Saukiinae, and the fixed cheeks are much wider.

The fossil is common in some of the highest layers exposed in the Hoyt quarry, from which the types were collected. The writer found many cranidia, free cheeks and pygidia closely associated, leaving no doubt that these fragments belong to one

species: The pygidium is even more unlike those of the Saukiinae than the cranidium; but both cranidium and pygidium fit perfectly in the writer's genus *Keithiella*.

Keithiella is based on *Arionellus cylindricus* Billings from the boulders in the Lévis conglomerate. The writer (Rasetti, 1945, p. 476) had already tentatively assigned to *Keithiella* a pygidium of the type of those collected from the Hoyt limestone. The new find leaves no doubt that this assignment is correct.

The cranidium was described by Walcott from exfoliated specimens. Some of the small cranidia preserve the test, showing a beautiful surface ornamentation. The surface is covered with strong tubercles, excepting the anterior rim where the ornamentation consists of transverse ridges. The surface ornamentation is fainter but still visible on the interior cast.

The free cheeks are moderately convex, of average width, and possess a wide convex rim. The rim is striated, the remaining surface strongly tuberculated as the cranidium. The genal spines are strong.

Pygidium subtriangular, more than twice wider than long. Axis strongly prominent, slightly tapered, almost reaching the posterior margin; extended into a short post-axial ridge. Four or five axial furrows fairly well impressed. Pleural lobes depressed, concave marginally. Pleural furrows wide; interpleural grooves narrower and shallower but visible. Each furrow and groove form a wide depression, separated from the next by a narrow, elevated ridge that extends across the concave border. Surface of pygidium smooth.

The cranidium of this species differs from that of *K. cylindrica* chiefly in the lesser elevation of the fixed cheeks, longer palpebral lobes, and tuberculation visible on the interior cast. It closely resembles *K. maior* Rasetti, but has a somewhat less elevated glabella and narrower rim. *K. maior* is known only from exfoliated specimens and the surface characters cannot be closely compared.

Formation and locality: Hoyt limestone; Hoyt quarry (upper beds), 4 miles west of Saratoga Springs, New York.

Lectotype: U. S. N. M. no. 58563; paratype: U. S. N. M. no. 58564; plesiotypes: Laval Univ. nos. 1043 a-e.

KEITHIELLA RAYMONDI Rasetti, n. sp.

Plate 1, Fig. 22.

Highgatea bisinuata Raymond (part), 1937, Geol. Soc. Am. Bull., vol. 48, p. 1088, pl. 1, fig. 14.

This species is based on a pygidium that Raymond assigned to *Highgatea bisinuata* (=*Loganellus*). The writer (Rasetti, 1945, p. 476) already remarked that the pygidium does not belong to this species and probably is a pygidium of *Keithiella*. The discovery of the pygidium of *Keithiella speciosa* proves that this assumption is correct, since the two pygidia are very similar.

The pygidium of the new species has depressed pleural lobes with a concave border, as in *K. speciosa*, but differs in possessing 5 instead of 3 distinct ribs crossing the concave border.

The writer thought at first that this pygidium might be assigned to *K. affinis* (Raymond) from the upper fossiliferous zone of the Gorge, but examination of the type material revealed that the same piece of rock that bears the type cranidium of the latter species also bears a pygidium that differs from the one under discussion and probably is the pygidium of *K. affinis*. This pygidium is proportionately longer and narrower than the pygidia of *K. speciosa* and of *K. raymondi* and the pleural lobes are more convex. It closely resembles a pygidium of *Keithiella* described by the writer (Rasetti, 1945, p. 476, pl. 62, fig. 22) as "unassigned pygidium no. 1."

Formation and locality: Gorge formation (lower zone); Highgate Falls, Vermont.

Holotype: Yale Peabody Museum no. 14706.

Genus PROSAUKIA Ulrich and Resser, 1933

PROSAUKIA EBORACENSIS (Resser)

Plate 1, Figs. 17-19.

Lonchocephalus calciferus Walcott (part), 1912, Smithsonian Misc. Coll., vol. 57, no. 9, p. 270, pl. 43, fig. 9.

Dicellocephalus hartti Walcott (part), 1912, idem, p. 273, pl. 44, figs. 7, 7a.

Dikelocephalus hartti Walcott (part), 1914, Smithsonian Misc. coll., vol. 57, no. 13, p. 368, pl. 63, figs. 7, 7a.

Saukia eboracensis Resser, 1942, Smithsonian Misc. Coll., vol. 101, no. 15, p. 49.

Resser based the species on a pygidium that Walcott had erroneously assigned to *Dikelocephalus hartti*, and also attributed to it a free cheek described by Walcott as *Lonchocephalus calciferus*. The writer collected numerous pygidia identical with the form in question, and also associated cranidia that doubtless belong to the same species. This material comes from the typical locality.

The discovery of the cranidium shows that the species cannot be left in *Saukia* as defined by Ulrich and Resser, since it possesses a well-defined preglabellar area. It fits well in *Prosaukia*, more precisely in the group of species with surface tuberculation and without neck spine. However, it must be mentioned that the limits assigned to the genera of the Saukiinae by Ulrich and Resser appear of somewhat doubtful validity. The authors themselves state (Ulrich and Resser 1933, p. 138) that several species not discussed in their paper as of "Ozarkian" age do not readily fall within any of their genera.

Cranidium typical of the Saukiinae. Glabella straight-sided, slightly tapered, truncated in front. Occipital segment without spine. Occipital furrow and posterior glabellar furrow well impressed across the glabella. Another pair of furrows is fairly well impressed at the sides and still visible mesially, although narrow and shallow. The anterior pair is very narrow and shallow, short, transverse and situated opposite the anterior end of the palpebral lobes. Fixed cheeks and palpebral lobes average for the genus. Brim divided into rim and preglabellar area by a well impressed anterior furrow; rim wider mesially than the preglabellar area.

Surface of glabella covered with distinct tubercles; fixed cheeks and brim with low, irregular ridges. The surface ornamentation is visible only on the outer surface of the test.

The pygidium has been figured by Walcott and described by Resser and nothing can be added.

The species closely resembles several of those described by Ulrich and Resser from the upper Mississippi Valley, but it is difficult to make a close comparison because the fine details of the surface are not preserved in the coarse sandstones of that area.

Formation and locality: Hoyt limestone; Adirondack Railroad quarry, 1 mile northwest of Saratoga Springs, New York.

Holotype: U. S. N. M. no. 58577; paratype: U. S. N. M. no. 58556; plesiotypes: Laval Univ. nos. 1044 a-c.

PROSAUKIA IRRASA (Raymond).

Plate 1, Figs. 20, 21.

Stenosaukia irrasa Raymond, 1937, Geol. Soc. Am. Bull., vol. 48, p. 1090, pl. 1, fig. 17.

The species and the genus were based on a small cranidium from the lower zone of the Gorge. Raymond separated this form from the other genera of the Saukiinae on the basis of the "downward-inflected anterior brim" and of the tapered glabella. As far as the first character is concerned, examination of the type shows that the brim is hardly more inclined than in the other genera of the group. The second character is even less distinctive, since in all species of *Prosaukia* and many of *Saukiella* there is no enlargement of the frontal portion of the glabella. It may be added that the type of *Stenosaukia irrasa* is a very small and probably immature individual, and that young cranidia of the species just discussed, *Prosaukia eboracensis*, are extremely similar to it. For all these reasons, there seems to be no ground for recognizing the genus *Stenosaukia* and the species will be assigned to *Prosaukia*.

Raymond's figure is misleading in several respects. The glabella does not taper as rapidly as shown. The brim is narrower than in the figure and has a shallow anterior furrow separating the rim from the preglabellar area. All these characters are apparent from a cast of the type and from a few additional cranidia collected by the writer. The latter are from the upper fossiliferous zone of the Gorge while Raymond's type is from the lower zone, but careful comparison failed to show any differences. One of the new cranidia is figured.

Compared with *P. eboracensis*, the present species differs in the proportionately narrower and longer glabella and the lesser divergence of the facial sutures in front of the eyes. The surface ornamentation seems to be about the same as in *P. eboracensis*, as far as can be ascertained from such small individuals.

Formation and locality: Gorge formation (lower and upper zones; type from the former); Highgate Falls, Vermont.

Holotype: Yale Peabody Museum no. 14707; plesiotype: Laval Univ. no. 1045a.

Genus RAYMONDINA Clark, 1924.

RAYMONDINA IMMARGINATA Rasetti, n. sp.

Plate 1, Figs. 10-13.

Cephalon small, highly convex. Glabella prominent above the fixed cheeks, parallel-sided, well rounded in front. Occipital furrow deep, occipital segment rather narrow. Glabellar furrows exceedingly shallow; posterior pair divided into two pairs of short, shallow pits exactly as in the genotype, *R. respecta*. Fixed cheeks convex, sloping down steeply at the sides. Palpebral lobes of medium size; their centers situated on a line through the anterior third of the glabella. Posterior branch of the facial suture directed first outward, then more directly backward and reaching the margin exactly at the genal angle. Anterior facial sutures parallel in front of the eyes, then curving inward and remaining slightly intramarginal for their entire course. Brim convex, without any defined rim. Free

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EXPLANATION OF PLATE.

Figs. 1-3. *Idiomesus tantillus* Raymond, x8; top, front and side views of cranidium; Laval U. 1042a, plesiotype. Gorge formation (upper zone); Highgate Falls, Vermont.

Figs. 4-9. *Keithiella speciosa* (Walcott), 4, 5, top and side views of cranidium preserving the test, x6; 6, larger exfoliated cranidium, x3; 7, small free cheek, x6; 8, 9, pygidia, x4; Laval U. 1043a-e, plesiotypes. Hoyt limestone; Hoyt quarry, 4 miles west of Saratoga Springs, New York.

Figs. 10-13. *Raymondina immarginata* Rasetti, n. sp., x8. 10-12, front, side and top views of cephalon; Laval U. 1046a, holotype; 13, cranidium; Laval U. 1046b, paratype. Upper Cambrian boulders in the Lévis formation; Guay's quarry, Lévis, Quebec.

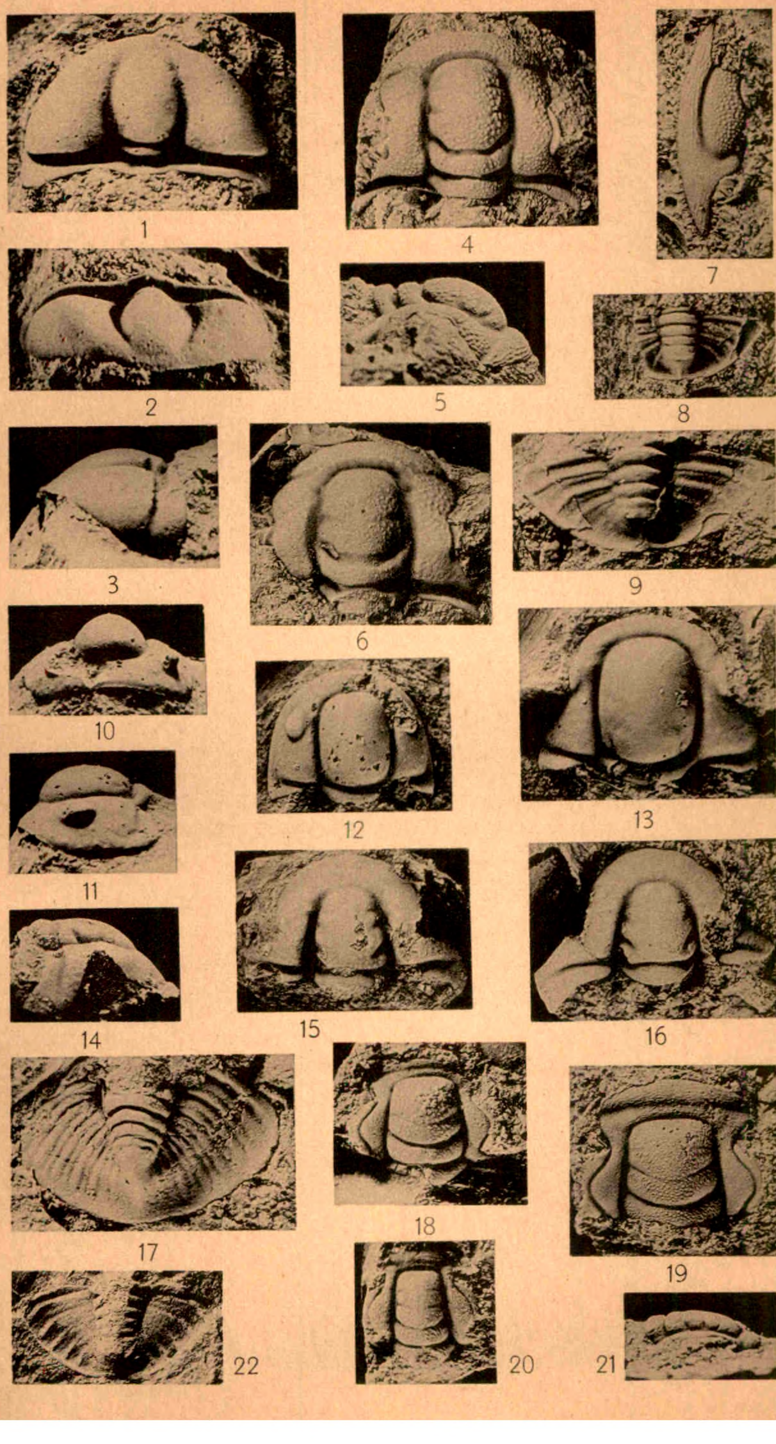
Figs. 14, 15. *Westonaspis laevifrons* Rasetti, x5; side and top views of cranidium; Laval U. 1047, plesiotype. Gorge formation (upper zone); Highgate Falls, Vermont.

Fig. 16. *Westonaspis laevifrons* Rasetti, x5; cranidium; Laval U. 1196, paratype. Upper Cambrian boulders in the Lévis formation; South Ridge, Lévis, Quebec.

Figs. 17-19. *Prosaukia eboracensis* (Resser), x4. 17, exfoliated pygidium; 18, 19, cranidia; Laval U. 1044a-c, plesiotypes. Hoyt limestone; Adirondack Railroad quarry, 1 mile northwest of Saratoga Springs, New York.

Figs. 20, 21. *Prosaukia irrasa* (Raymond), x6; top and side views of cranidium; Laval U. 1045a, plesiotype. Gorge formation (upper zone); Highgate Falls, Vermont.

Fig. 22. *Keithiella raymondi* Rasetti, n. sp., x2.5; pygidium (photograph of cast); Y. P. M. 14706, holotype. Gorge formation (lower zone); Highgate Falls, Vermont.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cheeks sloping rather steeply, without genal spines. Owing to the intramarginal course of the suture the free cheeks are visible dorsally on the anterior brim, but it has been impossible to ascertain whether they are separated by a median suture or fused.

Surface of test smooth except for a few scattered tubercles on the fixed and free cheeks. Similar tubercles are present in *R. respecta*. Length of largest cranidium 8 mm.

This species is almost identical with *R. respecta* in all characters, except the absence of a frontal rim. In general the presence or absence of the rim is considered a character of generic importance, but in this case the two species are so similar in all other respects and so obviously related that it would appear pointless to separate them generically. It may be added that the rim in *R. respecta* is low, and in some individuals less defined than in others.

This species shows some interesting features of ***Raymondina.*** The genotype is known only from cranidia, and Clark (1924), observing the rearward extension of the posterolateral limbs, deduced that the sutures reach the lateral margin in advance of the genal angle and considered the genus as proparian. He assumed that the free cheeks were narrow and anterior in position. Separated cranidia of *R. immarginata* show exactly the same type of sutures. However, the discovery of a complete, well preserved cephalon proves that the free cheeks are not narrow and short as supposed by Clark, but extend as far as the genal angle. It is a frequent feature of trilobites without genal spines that the posterior branch of the facial suture reaches the margin exactly at the genal angle, so that these trilobites might with equal right be called proparian or opisthoparian. The writer believes that, at least in this and several other cases, the distinction has little taxonomic importance.

Formation and locality: Upper Cambrian boulders (boulder 32, *Hungaia* zone) in the Lévis formation; Guay's quarry, Lévis, Quebec.

Holotype and paratype: Laval Univ. nos. 1046 a-b.

Genus WESTONASPIS Rasetti, 1945.

WESTONASPIS LAEVIFRONS Rasetti.

Plate 1, Figs. 14-16.

Westonaspis laevifrons Rasetti, 1945, Jour. Paleont., vol. 19, p. 475, pl. 62, figs. 16, 17.

In describing this species, the writer made an inaccurate statement which is corrected here. In the type, the posterolateral limbs of the cranidium are both broken off almost in a straight line back of the palpebral lobes. It was believed that the posterolateral limbs were complete and that their outline represented the posterior branch of the facial suture. The later find of a few cranidia of the species in the Gorge showed that the posterolateral limbs, when unbroken, are long and narrow, parallel-sided. The posterior branch of the facial suture is directed straight outward immediately behind the palpebral lobe.

After this feature had been noticed, a paratype cranidium from Lévis was further prepared and showed an identical posterolateral limb as observed in the specimens from the Gorge.

This find adds another species common to the Gorge and to the boulders of the *Hungaia* zone at Lévis.

Formation and locality: Upper Cambrian boulders (boulder 14) in the Lévis formation; South Ridge, Lévis, Quebec. Also Gorge formation (upper zone); Highgate Falls, Vermont.

Holotype and paratype: Laval Univ. nos. 1196 a-b; plesiotype (from the Gorge formation); Laval Univ. no. 1047.

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TWO UPPER CAMBRIAN (TREMPEALEAU) TRILOBITES FROM DUTCHESS COUNTY, NEW YORK.

CHRISTINA LOCHMAN.

ABSTRACT. Two new species of Upper Cambrian trilobites, *Prosaukia briarcliffensis* and *Plethometopus knopfi*, are described from a bed of the "Hoyt dolomite" in Dutchess County, New York. From this horizon only a *Lingulepis* has been previously obtained. The association of *Prosaukia* and *Plethometopus* indicates an horizon not earlier than the middle of the Franconian stage nor later than the middle of the Trempealeaulan stage.

RECENTLY Dr. Adolph Knopf, while accompanying Mrs. Knopf on field work, discovered a few fairly well preserved trilobite specimens in an horizon of the Upper Cambrian "Hoyt dolomite" (Knopf, 1927) from which only a single poor brachiopod specimen identified by Dr. G. A. Cooper as *Lingulepis* had ever been obtained. The small patch of fossiliferous dolomite occurred about 4 feet above the road surface in a prominent outcrop on the east side of Highway N. Y. 82A, 300 feet north of the entrance to Briarcliff Farm, and 1¼ miles due south of the village of Pine Plains, Dutchess County, New York.

The rock matrix of the "Hoyt dolomite" in which the fossils occur consists of a medium-gray, fine-grained, crystalline dolomite. It has been extensively fractured by small cracks some of which have subsequently been healed by thin white calcite veins. Weathering has produced limonite stains on many of the fracture surfaces, and limonite discoloration of the fossil surface.

All of the dolomite brought in from the field was broken up and examined, but all the specimens obtained came from several medium-sized pieces in which fossils were first noted. The specimens were apparently restricted to a rather small patch in a single horizon, where, by some fortuitous chance, they had escaped destruction. The collection is quite small as it consists of one pygidium, two cranidia and five fragmentary free cheeks of a *Prosaukia* species, and two cranidia and two fragmentary free cheeks of a *Plethometopus* species. Considering the scarcity of reported fossils, the presence and preservation of these few specimens is quite remarkable. None of the larger

specimens appears distorted, though several are crossed by healed cracks. On the *Prosaukia* pygidium the outer surface with ornamentation is still present. The large *Prosaukia* cranidium retains only the leached and discolored inner surface of the test. This specimen appears to lie on a bedding plane separating two beds which can be distinguished by a slight but definite change in coloration. The other *Prosaukia* specimens are either worn inner surfaces or dolomite molds and rather fragmentary. Among the *Plethometopus* specimens the two cranidia are largely only dolomite molds, and the free cheeks, while retaining broken patches of the outer surface, are quite incomplete. In spite of the noted deficiencies, the large cranidium and pygidium of *Prosaukia* and the large cranidium of *Plethometopus* are complete enough to insure accurate generic determination and reasonably correct specific identification.

The discovery of these specimens is especially valuable as it affords the first correlation of any portion of the Dutchess County "Hoyt dolomite" with the standard Upper Cambrian section. Both genera have a fairly long range through the upper half of the Upper Cambrian, and with both represented by new species and no other associated forms, the fauna could be dated anywhere from the *Ptychaspis-Prosaukia* zone of the Franconian up through the Upper *Dikelocephalus* zone of the Trempealeauian. However, an analysis of the relationship of these new species to the described species has led the author to favor dating this collection as somewhere in the lower half of the Trempealeauian.

The genus *Prosaukia* makes its first appearance in western United States and Wisconsin in the *Prosaukia* subzone of the Franconian, and continues in considerable abundance and variety through the *Briscoia* and Lower *Dikelocephalus* zone. In the Trempealeauian of Wisconsin the genus becomes quite rare and is last known from two inconspicuous species in the Upper *Dikelocephalus* zone. The three species of *Prosaukia*, *P. newtonensis* (Weller), *P. welleri* Resser and *P. tribulis* (Walcott) (Resser, 1942) described from eastern United States, are all presumed to be, in so far as can be determined by their poor and questionable faunal associations, of Trempealeauian age. *Plethometopus* is known from nine valid described species. Apparently the earliest species is *P. albertensis* Resser, described (Resser, 1942a) from the Lyell

formation of Alberta. This single peeled cranidium is a good *Plethometopus* but differs from all other species in the much clearer impression of the dorsal furrow and the presence of the lateral remnants of the marginal furrow. Such features would appear to be primitive in a genus distinguished by the obsolescence of the marginal furrow and the very weak development of the dorsal furrow; and it is not surprising to find the species associated with *Chariocephalus* and *Ellipsocephaloides*, genera which, in the Wisconsin standard section, occur in the *Ptychaspis-Prosaukia* and *Briscoia* zones of the Franconian. In Wisconsin *Plethometopus* appears in the Lower *Dikelocephalus* zone but is more common and abundant throughout the Trempealeauian, continuing to the end. Outside of Wisconsin, the genus occurs in the Eminence formation of Missouri, the Gorge formation of Vermont, both Trempealeau equivalents, and the *Hungaia magnifica* fauna in boulders of the Point Levis conglomerate, which is also considered a Trempealeau equivalent (Rasetti, 1944). Of all these species, *Plethometopus knopfi* Lochman, n. sp. is most similar to *P. acutus* Rasetti, *P. obtusus* Rasetti and *P. armatus* (Billings) of the *Hungaia magnifica* fauna.

Because of the above cited specific relationships and the geographic distribution, the author believes that actually this small fauna from Dutchess County is not earlier than the Lower *Dikelocephalus* zone nor later than the Upper *Dikelocephalus* zone, or somewhere in the lower half of the Trempealeauian stage.

DESCRIPTION OF SPECIES.

PROSAUKIA BRIARCLIFFENSIS Lochman, n. sp.

Plate 1, Figures 1-6.

Cranidium rectangular; glabella oblong, tapering very slightly forward to a broad truncated front; convexity low, regular in posterior half, curving steeply in front; two pairs of glabellar furrows, first pair short, well-defined, slightly curved, posterior pair narrow, deep, arcuate, not quite meeting in center; occipital furrow broad, deep, slightly sinuous; occipital ring wide, slightly convex, with a small posterior median node; dorsal furrow of medium width, well-defined; frontal limb very narrow, expanding a little at sides, horizontal,

flat; marginal furrow shallow, of medium width; frontal border apparently of medium width, flat, slightly downsloping; anterior margin unknown. Fixed cheeks very narrow, one quarter width of glabella at widest midline, upsloping; palpebral lobes large, wide, arcuate, on posterior one-third of glabella; palpebral furrows deep, medium width; postero-lateral limb approximately one-third length of occipital ring, crossed by a deep, well-defined intramarginal furrow. Free cheek rectangular with large eye along inner side; ocular platform of medium width anteriorly, expanding posteriorly, convex; marginal furrow narrow, well-defined, running into intramarginal furrow; marginal border narrow, convex with short anterior projection and a moderately long, heavy genal spine. Facial suture cutting anterior margin far out at sides, curving slightly out, then running in diagonally to and curving around palpebral lobe, thence curving out and back to cut posterior margin well within genal angle.

Thorax unknown.

Pygidium semicircular; axial lobe of medium width, strongly convex, tapering regularly posteriorly, extending fully two-thirds length of pygidium, divided by three anterior, well-defined and one narrow, faint furrow, into three wide segments and one narrow segment and a long, tapered terminal portion; pleural lobes slightly more than one-half axial lobe in width, low, gently downsloping into the medium wide, concave marginal border; no marginal furrow; pleural lobes divided into four segments by narrow, well-defined furrows crossed by narrow, parallel pleural furrows, both curving posteriorly onto and fading out across marginal border; greatest width of pygidium apparently on transverse midline; posterior margin regularly curved.

Surface of cranidium unknown; outer surface of free cheek crossed by low irregular ridges curving parallel to border; outer surface of pygidium coarsely granulated on axial and pleural lobes, granules passing into low, irregular ridges on the marginal border; inner surface unknown; ventral surface of doublure crossed by narrow concentric ridges.

REMARKS: The species is represented by one large adult cranidium, one small fragmentary cranidium, one large pygidium and a number of fragmentary free cheeks. Considering the matrix of the specimens, the preservation is quite good,

though none of the specimens is actually complete in outline. It has been assumed that the cranidium and pygidium represent the same species though in view of the small size of the collection, this assumption may be quite wrong. Because of the very fine generic distinctions drawn by Ulrich and Resser (1930, 1933) in their monograph on the Dikelocephalidae it is difficult to place specimens with certainty unless they are quite complete in outline. The author has decided, after considerable study, that these specimens fit the generic characters of *Prosaukia*, as established by Ulrich and Resser.

It is quite difficult to make comparisons with the Wisconsin species, as many of those described by Ulrich and Resser appear to be synonyms, one of the other, and the validity of the associated pygidia is uncertain both for the Wisconsin and the New York species. In the character of the cranidium, *P. incerta* Ulrich and Resser from the Norwalk is very similar. the only difference being in the absence of a frontal limb in front of the glabella in *P. incerta* U. and R. *P. welleri* Resser is also close, but besides lacking the frontal limb in front of the glabella it also shows a complete posterior glabellar furrow. It is interesting to note that as in *P. briarcliffensis*, the Trempealeauian species from Wisconsin have a much more swollen front of the glabella than the common Franconian species.

TYPES: holotype, cranidium and impression, Y.P.M. 17391
paratype, pygidium, Y.P.M. 17392
paratypes, free cheeks, Y.P.M. 17393a, 17393b.

PLETHOMETOPUS KNOPFI Lochman, n. sp.

Plate 1, Figures 7-9.

Cranidium quadrate; glabella broad, sides very slightly tapered, with broadly rounded front, convexity even but low; no glabellar furrows; dorsal furrow shallow, faint at sides and barely traceable across front of glabella; occipital furrow shallow, obsolete at outer edges; occipital ring narrow, apparently not extending to dorsal furrow, expanding at center; apparently no occipital spine; frontal limb and border inseparable due to obsolescence of marginal furrow, the area of medium width, regularly convex, continuing downslope of front of glabella; anterior margin evenly rounded. Fixed cheeks very

narrow, approximately one-eighth width of glabella, slightly convex, downsloping; palpebral lobes just under medium size, lying anterior to center of glabella; no palpebral furrow or ocular ridge; postero-lateral limbs triangular, a little wider than long, length one-third of occipital ring, crossed by a broad, shallow intramarginal furrow. Free cheek fragmentary—apparently narrow, elongate; ocular platform of medium width, flat, downsloping; marginal furrow obsolete; marginal border narrow, crossed by three or four narrow ridges; genal area unknown. Facial suture cutting anterior margin far out at sides, curving gently out and in to and around palpebral lobes; then curving rapidly back to cut posterior margin.

Thorax and pygidium not known.

Outer surface of test not known; inner surface apparently finely punctate.

REMARKS: This species is described from one medium-sized cranidium, a small fragmentary cranidium and two fragmentary free cheeks which are tentatively associated with the cranidia. Of the described species of this genus, *P. knopfi* most resembles several species described from the *Hungaia magnifica* fauna in boulders of the Point Levis conglomerate, Levis, Canada. It differs from *P. armatus* (Billings) and *P. obtusus* Rasetti in the proportionately broader glabella and the apparent absence of either a long or short occipital spine (although this latter feature may have been destroyed on the specimens of *P. knopfi*). The species is very close to *P. acutus* Rasetti, having the same broad type of glabella, but it differs noticeably in the much flatter profile of the anterior portion of the cranidium. The latter feature cannot be attributed to size differences, as it is present in both specimens of *P.*

EXPLANATION OF PLATE 1.

All figures x 2.

Fig. 1-6. *Prosaukia briarcliffensis* Lochman, n. sp. 1, 4, dorsal and profile views of holotype, cranidium, Y.P.M. 17391. 2, 3, paratypes, two, fragmentary associated free cheeks, Y.P.M. 17393b; Y.P.M. 17393a. 5, 6, profile and dorsal views of paratype, an associated pygidium, Y.P.M. 17392

Figs. 7-9. *Plethometopus knopfi* Lochman, n. sp. 8, 9, profile and dorsal views of holotype, a large cranidium, Y.P.M. 17394. 7, paratype, a large, fragmentary associated free cheek. Y.P.M. 17395b.

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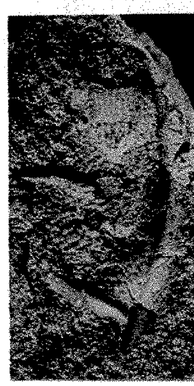

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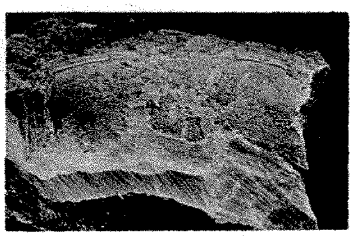

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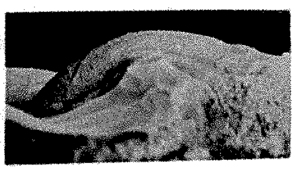

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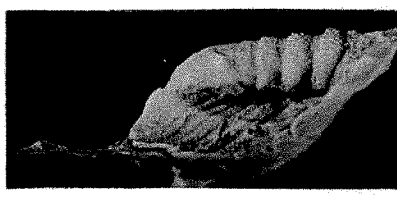

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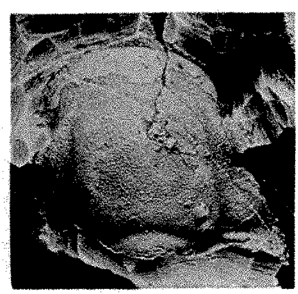

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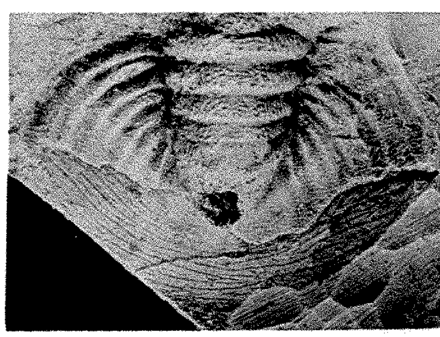

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knopfi, one of which is smaller and the other larger than the types of *P. acutus* Rasetti. As the three Levis species clearly demonstrate the presence of a faint complete dorsal furrow on peeled specimens and its obsolescence on the external surface of the test, the presence of such a furrow on the two specimens of *P. knopfi*, both internal molds, is considered directly attributable to the preservation.

TYPES: holotype, cranidium, Y.P.M. 17394
paratype, fragmentary cranidium, Y.P.M. 17395a
paratype, free cheek, Y.P.M. 17395b.

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WALNUTS FROM THE LATE TERTIARY OF ECUADOR.[1]

ROLAND W. BROWN.

ALTHOUGH several living species of walnuts are known from South America, the specimens described here represent the first reported fossil species from that continent. The fossils comprise 27 black, carbonized, brittle, slightly distorted pieces, mostly halves of nuts. They were collected in 1945 by Dr. A. A. Olsson, of the Imperial Oil Company of Canada, from the Punta Gorda formation, which crops out along the coast at Punta Gorda just west of the mouth of Rio Esmeraldas, Province of Esmeraldas, in northwestern Ecuador. Having been received at Johns Hopkins University after the death of Prof. E. W. Berry in September 1945, they were transmitted to me for study and description. Their age is late Miocene or early Pliocene in accord with the currently accepted age of the Punta Gorda formation in which a large, marine molluscan fauna is found. As the fossils are significantly different from any living or fossil species, I designate them as a new species named for Dr. Theodore A. Link, assistant Chief Geologist of the Imperial Oil Company, who assisted Dr. Olsson in collecting the specimens.

JUGLANS LINKI Brown, n. sp.

Plate 1, Figs. 1-9.

Nuts ovate-pyriform, rounded quadrangular in transverse section, cordate in longitudinal section, rather sharply acute at the apex, averaging 3 cm. in length and 2.5 cm. in diameter. Surface of the better specimens strongly rugose with deep furrows and sharp to rounded ridges. Wall extremely thick and meat cavity relatively small. In life these nuts were undoubtedly larger for there evidently was some shrinkage accompanied by distortion during the process of fossilization. Specimens deposited in the U. S. National Museum.

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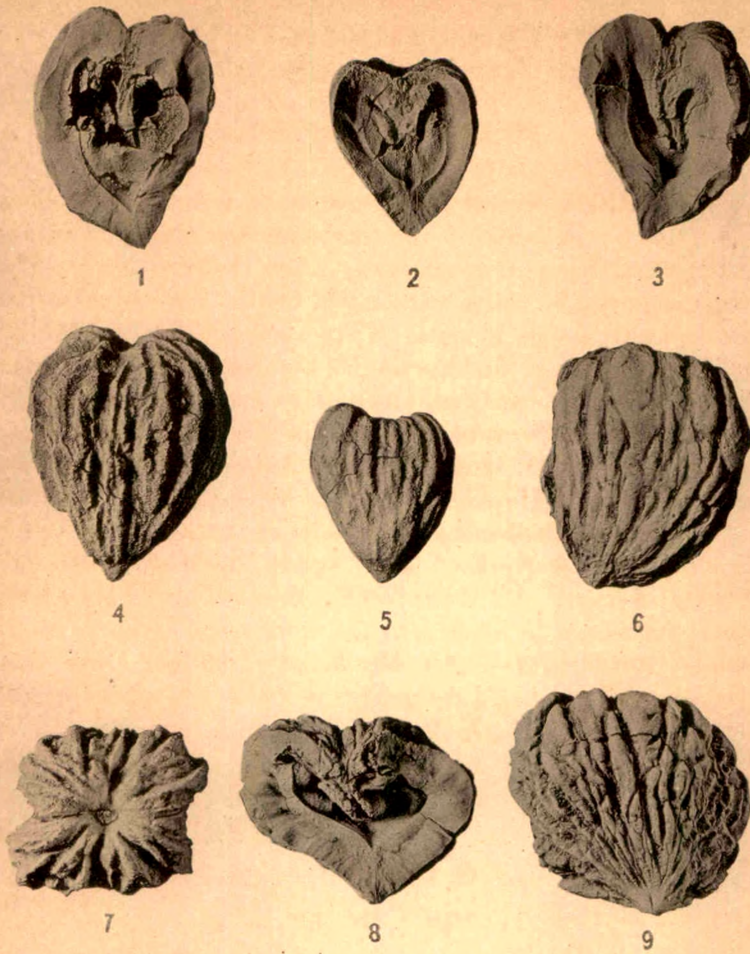

Figs. 1-9. Nuts of *Juglans linki* Brown, n.sp., from the late Tertiary of Punta Gorda, Ecuador. Natural size. Photos by Nelson W. Shupe.

The genus *Juglans* is represented today in Asia, Europe, and the Americas by about 20 species, although Dode (1906-1910) claimed 44 species, including varieties. Four native species are known from South America: *Juglans australis* (Argentina black walnut), *J. boliviana* (Bolivia black walnut), *J. columbiensis* (Colombia black walnut), and *J. honorei* (Ecuador black walnut), the common names indicating in general the regions inhabited by the different species. The fossil nuts resemble most closely those of *J. honorei* and its varieties but have acuter apexes and thicker walls. Consequently, their relationship, although suggestive, remains obscure and must probably continue so, inasmuch as no foliage was found with the nuts to aid comparison with living species.

The finding of these fossil walnuts in Ecuador enlarges somewhat the known area over which the genus *Juglans* was distributed in prehistoric times. This area was depicted on several occasions by E. W. Berry, the latest being in connection with the description of nuts called *J. siouxensis* (Barbour) Berry (1926, fig. 7) from the Oligocene of Nebraska. The map shows the known past range as including only the southern, warmer parts of the North Temperate zone and a small spot north of the Arctic Circle in southwestern Greenland. In time this distribution spans the interval from mid-Cretaceous to Pleistocene and Recent. Many of these records are based on identifications of foliage, sometimes very fragmentary, and are, therefore, probably not so reliable as those based on nuts. The earliest fossil nuts, recognizable with certainty as walnuts or at least as being closely related to walnuts, are some as yet undescribed specimens from the Paleocene of Montana, Wyoming, and Colorado. Associated with them are impressions of leaflets definitely attributable to the walnut family. From the Paleocene onward the record of walnuts becomes even more prominent both in America (Berry, 1912-1934) and abroad. After the late Pliocene, however, climatic changes shrank the area of distribution of the genus and localized the present living species. Whether the number of species has, in consequence, decreased, is unknown; but, according to Dode's account of *Juglans*, there seems to be considerable hybridization among living walnuts, presaging the emergence of new species.

Related to *Juglans* are the genera *Carya*, *Engelhardtia*, *Oreomunnea*, *Platycarya*, and *Pterocarya*, the entire group

constituting the walnut family, Juglandaceae. The last four genera have few species and are distinguished by bearing winged fruits. Together with *Carya* they have a much more restricted present distribution than *Juglans*, but all are represented in the fossil record from the Eocene onward.

The Juglandaceae are monoecious, the greenish, inconspicuous staminate and pistillate flowers being separate but on the same tree. The staminate flowers are in aments or catkins, the pistillate solitary or in few-flowered spikes. This simple arrangement reflects an adaptation to wind-pollination, as in most Amentiferae. Do these reproductive and other structures of the walnuts indicate primitiveness or reduction from more highly evolved forms? Botanists today seem to favor the reduction hypothesis, the case for which has been stated by Robertson (1904). To this may now be added the testimony of the fossil record. The presence of recognizable walnuts in the Paleocene presupposes some evolution of *Juglans* during the Cretaceous. However, until better evidence than the indefinite mid-Cretaceous foliage now assigned to *Juglans* is found, there is justification for believing that the genus as we now know it is a late or derived rather than an early phenomenon among dicotyledons.

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U. S. National Museum,
Washington, D. C.

A BURIED CHANNEL OF THE ST. LAWRENCE RIVER.[1]

ALICE E. WILSON.

THE east end of Barnhart Island in the upper St. Lawrence is about three miles west of Cornwall and is the proposed site of the big dam and power-house of the St. Lawrence Power and Waterway project. The island is approximately three miles long. Geographically within the State of New York, it was bought by Federal Government of the United States when the first serious investigations were made concerning the international power and waterway project. North of the western half of the island and roughly paralleling it, lies Sheek Island on the Canadian side of the river. For more than a mile above the two islands the river is a rushing, foaming rapid, the Long Sault. Above the rapid the Cornwall canal leaves the river on the north side and again joins it below Cornwall.

Where the river touches Sheek and Barnhart Island it divides into three channels, and the rapid becomes less turbulent. Two of the channels are shallow, that to the north of Sheek Island where there is now a dam and small power-house, and that between the two islands. The latter is the private preserve of gulls which fly to the upper end, float down the rapid and then circle back again, apparently with an enjoyment almost human. The third channel, south of Barnhart Island is the 'deep channel' down which float the steamers 'shooting' the rapids.

The proposed position of the first section of the new canal lies south of the river, along a natural depression that runs west from near the mouth of Grass river. Between the proposed canal and the present St. Lawrence river, deeply buried beneath glacial debris, is the former channel of this part of the river.

Some years ago the writer was assigned the geological mapping of the Cornwall map sheet. The southern part of the area has very few outcrops. The boiling Long Sault above Barnhart and Sheek Island and the lesser rapids on either side of them suggest rock near the surface in the river bed. But it was found by drilling that boulders form the floor of the river. In some places the bedrock lies at a considerable depth below this

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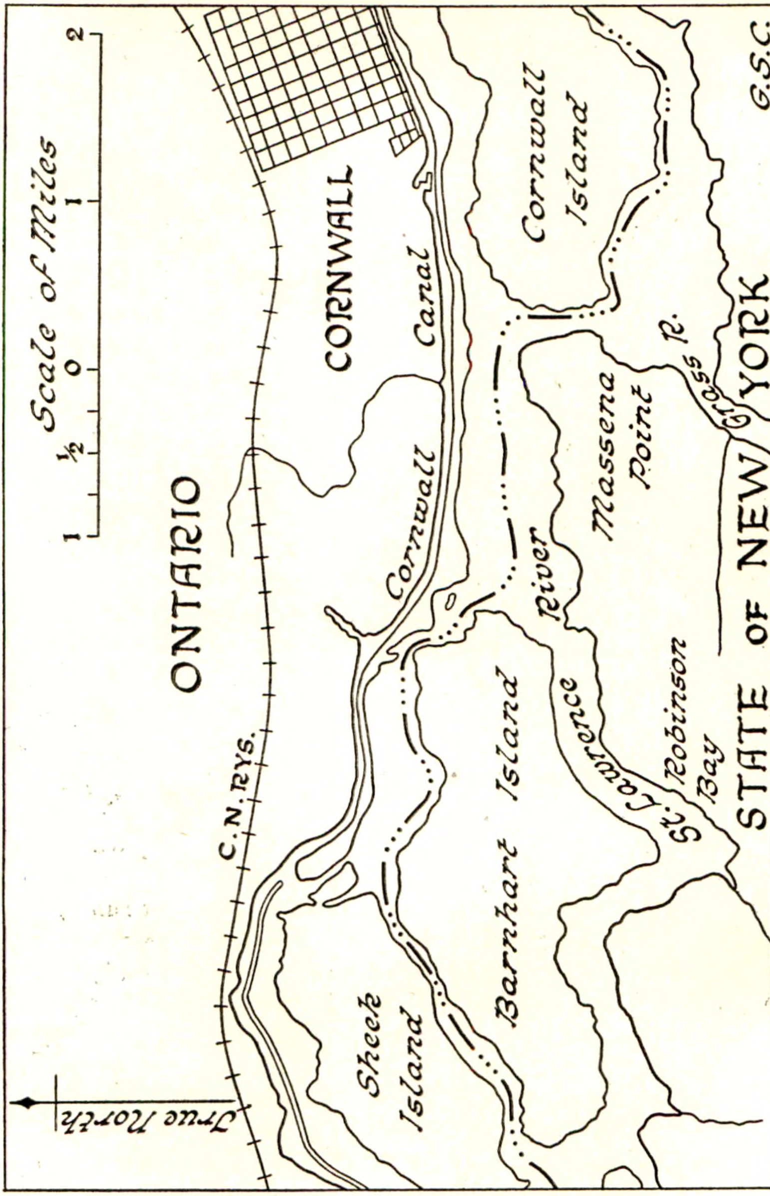
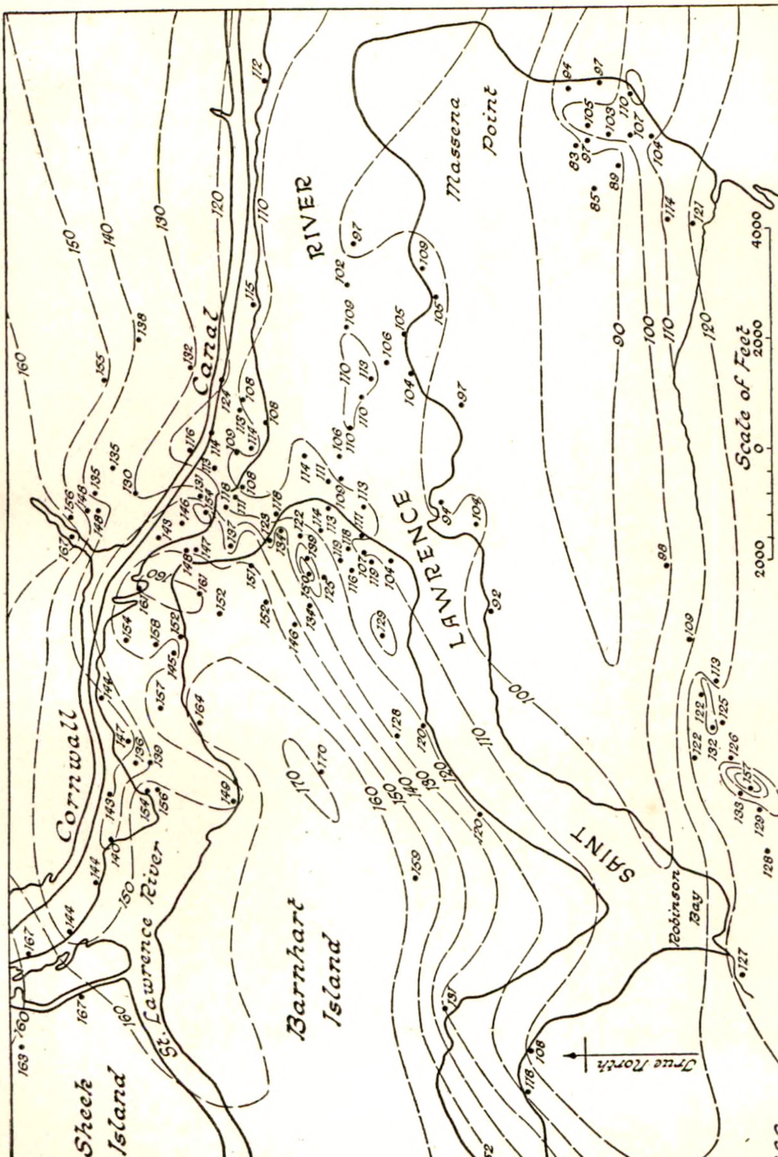


Text Fig. 1. Index map in the vicinity of Cornwall, Ontario.

boulder bed. The surrounding country in most places is deeply covered by sediments of the Champlain sea, by glacial debris reworked by the Champlain sea, and by terminal moraines and drumlins. The few outcrops of limestone here and there on



Text Fig. 2. Bed rock contours and bore-holes, shown in feet, of rock sub-surfaced near Cornwall, Ontario.

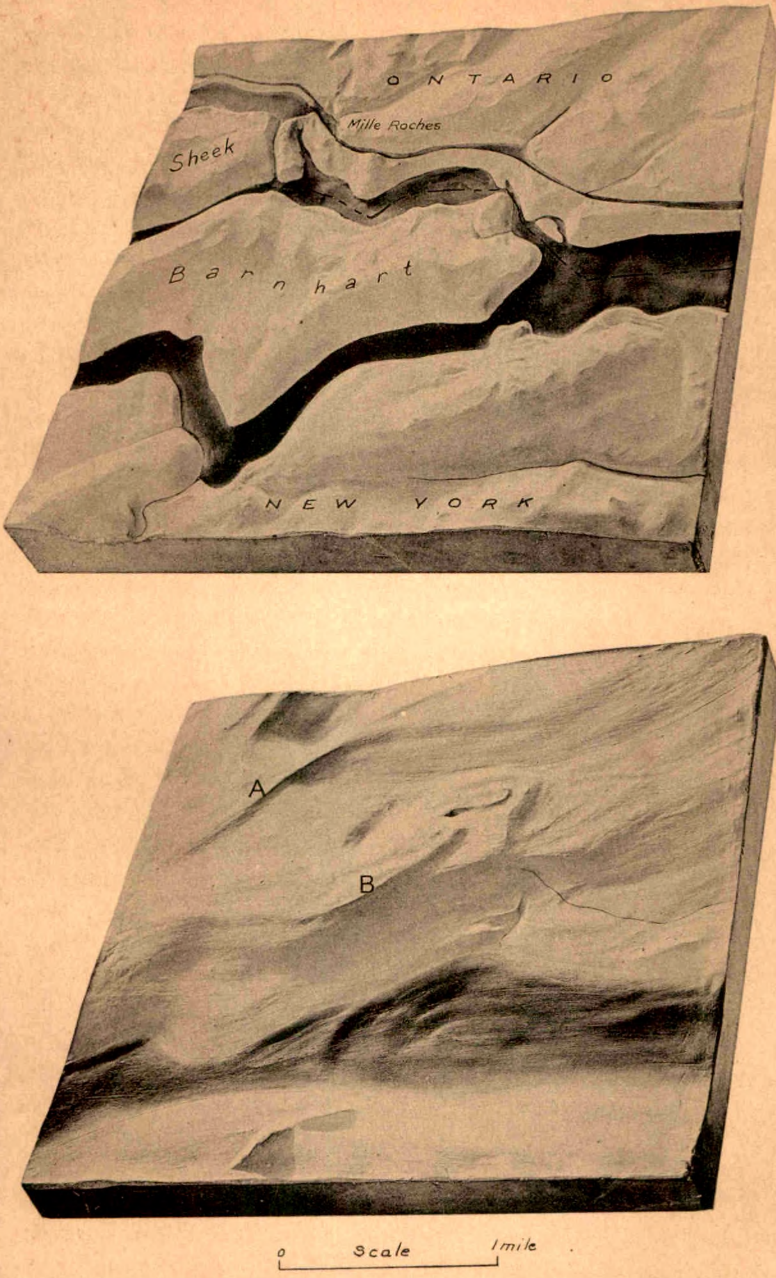
the north shore are of late Chazy age. The exposures on the Canadian side are all shown on the outcrop map issued in 1941 by the Geological Survey of Canada. Fortunately for the geological interpretation both Canadian and United States engineers, as well as those of Hydro Electric Power Commission

of Ontario, made many borings up and down the Ontario and New York shores and in the river bed itself. The elevation above sea-level of the bedrock in each boring was recorded and its position indicated on a map. All this information was readily made available to the writer, with the blue prints of the map. The records of the borings were examined and in most cases the cores themselves. During these first years of investigation most of the drilling penetrated bedrock from ten to twenty feet only. In the early years of World War Two, before the United States entered the conflict, investigations were again undertaken by the United States Engineers and some new information was added regarding the subsurface bedrock.

In studying the records and the blue prints in an attempt to visualize the form of the ancient rock surface it was noticed that on the mainland, south of the 'deep channel,' were a number of low rock elevations, not scattered at random but grouped so that they form a band of varying width, outlining a former course of the channel.

This low outline crosses the peninsula-like stretch of land from south of Massena Point to Robinson Bay. To reconstruct this ancient surface and to compare it with the present one a contour map of the bedrock surface was made. It is recognized that different individuals might readily unite points of equal elevations in different ways, hence the drawing of the contours was presented as a problem to several persons. The variations were so slight as to be almost negligible. The subsurface contour map was later revised according to the additional information brought to light by the more recent investigations. The revision extends the area a little farther east and not quite so far north. The main additions to this small region have been subtractions rather, and are on the north shore, for the elevations there are a little more gradual than at first supposed. The later information, however, in no way changed the apparent relationship of the ancient river bed to the present one. In a few minor instances the writer's interpretation varies slightly from that shown in the contours of the subsurface in the recent blue prints, but there is a reason for these variations in each case.

The subsurface has a low relief, the maximum difference in elevation being only about 90 feet. A broad channel is shown with its lowest part south of the present 'deep channel.' A cross section of the valley from its lowest contour to its highest



Relief map of Barnhart island region upper, present surface,
lower, subsurface.

contour shows a rise of barely 20 feet in half a mile, and then a rise of approximately 70 feet in half a mile. Towards the east the valley widens considerably. Beneath the city of Cornwall, not shown on Figure 2, there is a narrow line of low elevations which suggest an ancient stream flowing into the river from a northeasterly direction. United States engineers, I believe, have found another line of low elevations still farther to the south. It has not been determined how or where it connected with the main St. Lawrence.

The highland of Barnhart Island is fore-shadowed, and the gradual rise on the north suggests the present northern boundary of the river. The few existing exposures of bedrock are along the higher contour of this buried bank. Two peculiar ridges (A and B, Pl. 1) of higher land cross the upper half of the area roughly at N. 45 degrees E. These ridges are two of a series, several of which cross the river elsewhere at approximately the same angle. A number of low knobs are scattered over the subsurface, all oriented in the same direction as the ridges. They probably owe their orientation to glacial movement, perhaps modified by the course of the river. No glacial striae have been found on the few outcrops, but elsewhere in the general district they have a northeast direction. There is an irregular trench north of the east end of the embryo Barnhart Island, fore-runner of the channel between Barnhart and Sheek islands. Its western end is the steep slope of ridge A. At its eastern end it has an outlet to the main river channel through a narrow gorge cut across ridge B. Though very much smaller, the nature and direction of the trench are somewhat similar to the cut at 'The Gulf,' Covey Hill, Quebec and New York State, and it may have a similar origin. The present much narrower channel between Sheek island and the mainland was evidently cut after the deposition of the glacial debris. Beyond the northwest corner of the area, shown in Text Fig. 2, just north of contour 160, there is a curious deep depression which, as far as can be seen, does not connect with the trench. Neither the two peculiar ridges nor this curious depression can be interpreted without further information over a wider area.

But the feature of most interest here is a small but abrupt elevation a little south and east of the southern tip of Robinson Bay. The reason for the preservation of this knobby ridge is not clear. The country rock is Beekmantown dolomite which suggests no variation in resistance. But this knob apparently

played its part in the subsequent history of the region. From this highest elevation the southern boundary of the ancient St. Lawrence valley has a very gradual slope to the east. The deepest part of the old channel lies just to the north.

Two relief maps were made of exactly the same area. That of the present surface was built up from the existing Canadian and United States contour maps. The relief map of the subsurface was built up from the reconstructed contour map of rock elevations before the recent revision, which revision, as mentioned above, in no way changes the main features. These two maps are photographed on Plate 1.

A comparison of the two shows the development of Sheek and Barnhart islands. It also shows that the former lower part of the channel now lies buried beneath a deep overmantle. The present depression lies south of it. Why this reversal of elevations?

One explanation may be that the curious knob of high land southeast of Robinson Bay was an obstacle in the path of glacier movements. Debris was dropped in front of it, fanning out towards the east and resting against the comparatively high slope of the south bank. The material deposited would itself prove a further obstruction to a dying glacier. The debris filled the channel to the north and piled up higher and higher. This glacier ridge, roughly east-west in direction, now covers the peninsula-like section between Grass river and Robinson Bay. Its southern boundary slopes down towards the buried rocky bank of the old channel. Along this southern margin is the present depression, occupied by a stream practically flowing on top of the former channel shore. The present stream owes its origin to the combined effect of the subsurface contours and the glacial deposits, though since its inception it has, of course, further eroded the glacial debris.

The proposed entrance of the new canal, as indicated on the published map, is in the present depression at the mouth of this stream. The peculiar knobby ridge southeast of Robinson Bay is not very conspicuous on the present surface, but it continues to impress its will on man as well as upon glacial material. The old channel and the new canal converge as they approach the obstruction but they do not meet. The ancient channel passes to the north. The new canal in its course south of Robinson Bay must bend southerly to pass it by.

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RATE AND MASS OF DEEP-SEA SEDIMENTATION.

PH. H. KUENEN.

ABSTRACT. The average rate of deep-sea sedimentation as found by several independent methods is found to agree very satisfactorily (see table II). Several independent methods for estimating the total mass of deep-sea sediment show results of the same order of magnitude. Former estimates showed divergencies of some 100,000 times. These hopelessly wide limits are now reduced to about one in four (see table IV).

A. RATE OF DEEP-SEA SEDIMENTATION.

ESTIMATES of the rate of sedimentation in the deep-sea have differed to such an extent that the total mass of sediment on the ocean floor has as yet not been evaluated to general satisfaction. On the one hand it has been held that the dredging of Tertiary sharks' teeth proved an almost total lack of deposition over areas occupied by red clay and therefore over most of the deep-sea floor. Others, like Murray and Hjort (1912, p. 170), calculated a rate of deposition for globigerina ooze of 2 to 5 cm. per 10 years from the state of preservation of transoceanic telegraph cables. There is nothing to show that the former observation gives a fair picture of average conditions, for a bottom current may reduce or even entirely prohibit deposition on certain limited areas while elsewhere in still water the sedimentation could be infinitely quicker. The second method leads to an impossibly high figure and is evidently based on erroneous interpretation; the heavy cable sinks into and thus becomes embedded in the mobile sediment, but it is not covered by deposition in a few years time.

We are now in a much better position to judge the rate of abyssal sedimentation, as three or four independent methods for measurement are available and these give comparable results.

Schwinner (1936, p. 149) evaluated the total fall of meteoritic dust on the earth at 500 tons per year. Using the measured content of nickel iron and silicate spherules in red clay and globigerina ooze he found a rate of sedimentation of 0.2 cm. and 4 cm. per thousand years respectively. Schwinner added a correction for oxidation and decomposition of the globules, and compaction. The rate of sedimentation should possibly be divided by about three. In the opinion of the present writer

this correction is not justified. Murray and Renard described the crust of magnetite developed around the meteoritic iron during the passage through the atmosphere. The cupule resulting from the contraction of the molten outer crust is generally clearly marked. The preservation of these exterior characteristics is strong evidence against a subsequent attack on the spherules by weathering in the seawater or on the sea floor. The correction introduced by Schwinner will therefore be discarded.

On the other hand the authors of the Challenger Report point out that the red clays, in which the quantity of spherules was determined, contained a relatively large amount of rare products such as shark's teeth, etc. In other red clays a much smaller amount of meteoric dust occurred. The figure calculated by Schwinner is consequently well below the average for all red clays. I will therefore take twice the rate of deposition for red clay, that is 0.4 cm. per 1000 years as the outcome of the "meteorite method".

Lohmann (1909) chose a similar method but used the production of coccoliths as basis for his calculation.

For a sediment rich in these particles ($\pm 60\%$) he found a rate of deposition of 0.1 cm. per 1000 years. (According to Correns (Symposium, 1939, p. 388) the original estimate of 0.2 mm. was halved.) As globigerina ooze contains on an average about 1/10 to 1/20 of this amount of coccoliths—as far as I have been able to ascertain—the rate of deposition would amount to 1 to 2 cm. per 1000 years.

W. Schott (1939) used a general stratification of the deepsea deposits in the tropical Atlantic and southwestern Indian Ocean. Taking the upper stratum as representing Post-

TABLE I.

Sedimentation according to Schott, in centimeters.

		Blue mud	Glob. ooze	Diatom ooze	Red clay
Average Thickness	Atl. O.	86	24		17
	Ind. O.		12	11	
Smallest, average, and largest per 1000 years.	Atl. O.	0.9 *1.8* 3.3	0.5 *1.2* 2.1		<0.5 <*0.9* 1.
	Ind. O.		0.3 *0.6* 1.0	0.3 *0.5* 0.7	

Glacial time, thus having been formed in 20,000 years, he found the values given in table I.

The lower values of the Indian Ocean are attributed by Schott to a smaller contribution of sediment from the continents. But the thickness of the Post-Glacial layer increases northwards in the Indian Ocean. It is 6 cm. at the southern boundary of the globigerina ooze, increasing to 15-20 cm. at 40° Southern latitude. It appears likely, therefore, that around the equator the Atlantic average of 24 cm. is attained also in the Indian Ocean. Probably the southern margin of the globigerina ooze has gradually migrated southward. The Post-Glacial stratum would thus represent an eyer shorter period on approaching higher latitudes. This interpretation appears more probable for a pelagic deposit, as it is only in minor degree dependent on supply of terrigenous matter.

Piggot and Urry (1942) recently developed by far the most accurate and trustworthy method of calculating the rate of deposition. They determined the radioactivity at a large number of points along deep-sea cores. The activity is caused by a constant amount of uranium and by an additional amount of ionium and radium. The latter two elements are reduced in time from their initial ratio to the amounts that are in radioactive equilibrium with the available uranium. The authors mentioned show how mathematical analysis of the variation of radioactivity with distance from the surface in the sample core leads to a dating of each point analysed. The younger parts can be dated to within one or two hundred years. Thus for the same volcanic ash in two samples an age of 13,300 and 13,100 years are found. The greatest age that can be ascertained with any degree of accuracy is 300,000 years.

The assumption is made that the ratio in which uranium, ionium, and radium are deposited at any one place in the oceans has remained constant during the period represented in the sample, although a different ratio is found for various areas and various types of deposit. The objection might be raised, that sedimentary petrography shows how in general the vertical variation is greater than the horizontal variation. Therefore a gradually or abruptly varying ratio for the three elements at one point of the sea floor might appear more probable. It should be kept in mind, however, that most of the factors causing vertical variations in continental sediments do not influence

pelagic deposits. Much thicker strata may form on the floors of the ocean, without alteration in the nature or distance of the source, than in continental basins. Moreover, the deposition of the radioactive elements has not yet been elucidated, but is evidently not that of normal settling of particles. What factors would cause variation in the ratio of deposition can therefore not yet be evaluated. Finally the very regular curves representing the radioactivity with depth ascertained by Piggot and Urry, even where lithological strata are passed, form strong evidence in favor of their assumption of a constant ratio of deposition at the site of each bottom sample (core).

Up to the time of writing only a few cores have been treated by this method. The results for a core of red clay taken 500 km. off the coast of California is 0.5 cm., and for a globigerina ooze in the Caribbean sea of 0.6 cm., per 1000 years. In the northern Atlantic the blue mud close to the coast of Newfoundland, at the end of the Labrador current, shows 24 cm. per 1000 years and another core to the east of the Mid-Atlantic ridge 11 cm. In the center of the western basin the average rate for a terrigenous globigerina ooze was ascertained at 4 cm. per 1000 years.

In the East Indies Miss Neeb (1943, p. 234) was able to recognize the volcanic ash deposited from the eruption of the Tambora on Soembawa in 1815 and that of the Oena Oena volcano in the Gulf of Tomini of 1899. Four Tambora samples showed an average deposition of at least 23 cm. in 115 years, of which half was volcanic, one third terrigenous materials and one tenth lime. The rate of deposition is thus found to be 200 cm. per 1000 years, of which 100 cm. are ash, 75 cm. terrigenous, and 20 cm. $CaCO_3$ (coral, limestone detritus, pelagic tests, etc.). An Oena Oena core showed 2 cm. in 30 years or 66 cm. per 1000 years.

The average of 90 cm. non-volcanic material per 1000 years is probably too high for the whole Moluccan area, as the samples were taken close to larger islands (north of the Lesser Sunda Islands and between Borneo and Celebes).

Only in the one core of Oena Oena material could Miss Neeb determine the rate of sedimentation of globigerina tests. She found 0.072 cm. per 30 years or 2.4 cm. per 1000 years. As globigerina oozes contain—besides tests—a certain amount of

terrigenous matter, a figure of 3 cm. per 1000 years may be assumed for that type of deposition in the East Indies.

Kuenen (1943, p. 31) attempted to estimate the average deposition from the denudation in the Moluccan area. He obtained 50 cm. terrigenous matter. For estimating the average rate of sedimentation of tests, shells, etc. in the Moluccas we can use the average percentage of $CaCO_3$, 19.7% (against 45.9% for all Challenger samples). This amount must be somewhat too high, because the calcareous matter is deposited more slowly and is therefore overestimated. On the other hand 1.4% must be added for siliceous organisms. Therefore 19% $CaCO_3$ will be assumed. Added to the 50 cm. terrigenous matter we obtain 62 cm. per 1000 years for blue mud. As detrital lime is included twice by this method 60 cm. is the ultimate figure. Using the percentage of volcanic ash in the sediments and starting from the estimated contribution by volcanoes, double this amount is found, but this method is more open to doubt. Hence the figure of 70 cm. per 1000 years for blue mud will be assumed. (For all deposits including volcanic matter 80 cm.)

Revelle and Shepard (1939, p. 273) deduced the rate of sedimentation in basins off the Californian coast at 25 cm. per 1000 years from the denudation. As loss to the open ocean should be subtracted, a figure of 20 cm. per 1000 years appears more probable.

In the Black Sea (Trask 1939, p. 488) a yearly rhythm of 0.2 mm., consisting of a light and a dark stratum, is found in bottom samples. The rates of sedimentation obtained by the examination of core samples all need a correction. The strata on the sea floor are reduced in thickness on being forced into the sampler. Piggot and Urry established experimentally that this reduction is of the order of 20%.

The results obtained by the various methods are summarized in table II.

The averages of the rate of sedimentation for each of the various types of deep-sea deposits as found by independent methods fit each other remarkably well. The divergence of estimates that used to run to at least 100,000 times, now appears to be reduced to 5 times for red clay or globigerina ooze. The larger divergences for blue mud are doubtless due to actual differences in the rate of sedimentation in various localities. Even the rates of deposition calculated from denuda-

TABLE II.

Rates of oceanic sedimentation according to various methods.

	Red clay	Glob. ooze	Blue mud	Diat. ooze
Meteorites	*0.4*	*4*		
Coccoliths		*1–2*		
Glacial strata				
(Atl. + Indian)	0.9	1.0	1.8	0.5
Corrected	*1.1*	*1.2*	*2.2*	*0.6*
Radioactivity	0.5	0.6 (4)	10 (24)	
(Atl. Pacific)				
Corrected	*0.6*	*0.7 (4.8)*	*12 (29)*	
Moluccas		8	95	
Corrected		*3.6*	*110*	
Calculated			70	
Yearly rhythm				
(Black Sea)			20	
Corrected			*24*	
Off California				
Calculated			*20*	

tion, are in fair accordance with the values found by measurement for the same region.

The principal need at present is for more extensive application of the method used by Piggot and Urry, especially to red clays from the central Pacific and deposits from the southern oceans. Nevertheless the order of magnitude is now established beyond doubt for the Quaternary period.

A vexed problem is whether the present rate of pelagic sedimentation is representative of the whole geologic past, or at least since the Precambrian, or whether the high relief of the continents and the Glacial Epoch have caused as great an increase of sedimentation in the deep-sea as must be assumed for denudation on land.

Reasons were given in my paper of 1941 for strongly doubting that the glacial epoch has caused a substantial increase in pelagic sedimentation. In my opinion an average rate of deposition in the deep-sea of 0.5 cm. per 1000 years for the geological past is the best estimate that can at present be made.

B. MASS OF DEEP-SEA SEDIMENTATION.

The most important method for estimating the total amount of sediments in the earth was employed by Clarke (1924, pp. 23-

36). First the average composition of igneous rocks is determined. From the average composition of shale, sandstone, and limestone the relative amounts of these products of weathering are ascertained. It is then found that a large proportion of the sodium is missing from the sedimentary rocks. The sodium in the oceans is supposed to represent the leached-out material that has gradually accumulated during the weathering of more and more igneous material. By a simple calculation the known store of sodium in oceanic waters is then converted to the total mass of weathered igneous rock. Clarke's conclusion was that 3.7×10^8 km.^{3} of sediment is the highest figure possible.

Goldschmidt (1933) averaged a number of Norwegian boulder clays and assumed that these must give a fair picture of the average composition of the earth's crust. He found almost the same composition as Clarke had calculated.

But later Kuenen (1941) pointed out several corrections that should be applied to Clarke's calculations, and in consequence the minimum amount was found of $5\frac{1}{2} \times 10^8$ km.^{3} Incidentally a much closer resemblance between assumed source material and resulting sediments was obtained (see table III).

TABLE III.

	Average composition of rocks								
	I	II	III	IV	V	VI	VII	VIII	IX*
	Shale	Sandst.	Limest.	Red clay	Terrig. clay	Globig. ooze	Source	All sediment	% difference
SiO_2	58.11	78.81	5.19	54.48	57.05	26.64	57.88	58.16	+ ½
Al_2O_3	15.40	4.76	0.81	15.94	17.22	9.75	15.68	15.98	+ 1⅓
F_2O_3	6.70	1.40	0.54	9.60	7.60	8.75	8.17	8.54	+ 5
MnO	trace	trace	0.05	0.99	0.12	0.27	0.17	0.64	?†
MgO	2.44	1.16	7.89	8.81	2.17	1.88	8.77	8.58	− 5
CaO	8.10	5.50	42.57	1.96	2.04	28.87	5.87	6.26	+ 7
Na_2O	1.80	0.45	0.05	2.05	1.05	0.98	8.47	1.89	−45
K_2O	8.24	1.32	0.33	2.85	2.25	1.32	2.59	2.82	+ 9
TiO_2	0.65	0.25	0.06	0.98	1.27	0.29	0.98	0.94	− 5
P_2O_5	0.17	0.08	0.04	0.30	0.21	0.18	0.28	0.26	− 8

* Differences between column VII and VIII in percentage of each constituent of the source material.

† Large discrepancy owing to reasons given in my paper of 1941.

Several considerations were brought forward by Kuenen (1941) that render an even larger total mass of sediments probable. We will accept 7×10^8 km.^{3} as the outcome of geochemi-

cal calculation for all sedimentary material in the earth's crust. For the deep-sea deposits 5×10^8 km.^{3} is thus established, because continental sediments are of the order of 2×10^8 km.^{3}

A second geochemical trend in sedimentation was indicated by Steidtmann. The relative amounts of the various types of sediment as measured in a large number of sections is found to be very different from that calculated by Clarke. If this method is applied to the data assembled by Kuenen (1941) the following results are obtained. The calculated ratio of shale: sandstone: limestone is 20: 3: 2 and the measured ratio is 20: 12: 14. If no lime had been deposited in the deep-sea the loss of clay and quartz to that environment would amount to 74% of the source material. Taking the total mass of sediments on the continents as 2×10^8 km.^{3} the deep-sea sediments would amount to 6×10^8 km.^{3} To this must be added 12½ times the volume of calcareous matter deposited in the deep-sea, or roughly $2\frac{1}{2} \times 10^8$ km.^{3} This method leads us to a total mass of deep-sea sediment measuring $8\frac{1}{2} \times 10^8$ km.^{3}

A third method is to estimate the total amount of denudation and to add production from volcanic eruptions (Kuenen, 1937). The outcome by this procedure is 10×10^8 km.^{3} Admittedly this figure is only a very rough estimate, but it goes to show, that no inadmissible assumptions are required to account for a total mass of sediment that is several times 10^8 km.^{3}.

A fourth method of approach is by the percentage of TiO_2 and P_2O_5 contained in the source materials and in various types of sediment. From our table III it will be seen that, compared to the source material, the continental deposits, shale, sandstone, and limestone, show a marked deficiency in both these elements. In order to balance this loss a considerable amount of terrigenous deep-sea clay is required in the case of titanium, and an even larger quantity of red clay in the case of phosphorus.

The accuracy of the data does not appear sufficient to warrant an exact calculation of the amount of deep-sea deposits from these two elements alone, but one may conclude that the volume is several times that of the continental sediments. With Clarke's original estimates no less than 50 and 40% of the TiO_2 and P_2O_5 contained in the source material is unaccounted for. Only by incorporating an ample mass of deep-sea deposits can the geochemistry of these two constituents be brought into balance.

The fifth method for estimating the total mass of sediment is to use the rate of sedimentation of deep-sea oozes and to multiply this by the age of the earth. As the relief of the continents is greater than was generally the case in the past, and as epicontinental seas are at present poorly developed, a smaller average rate of sedimentation will be assumed for the past. From table II an average rate of sedimentation at present in the deep sea (in which red clay plays a predominant part) of 1 cm. per 1000 years follows. An estimate of $\frac{1}{2}$ cm. for the past appears a reasonable deduction. Calculated as solid mass this would come to 1/7 cm. per 1000 years. In the course of 2×10^9 years this would amount to 2.9 km. This works out at $8\frac{1}{2} \times 10^8$ km.^{3}

In order to illustrate the surprising agreement between the 5 independent estimates of the total mass of deep-sea deposits on the floor of the oceans, the results are brought together in table IV.

TABLE IV

Total mass of deep-sea deposits according to various methods of calculation (without pore-space).

1.	From the Na in the ocean	5×10^8 km^3
2.	From the composition of continental sediments	8.5×10^8 km^3
3.	From denudation and volcanic eruptions	10×10^8 km^3
4.	From the geochemistry of TiO_2 and P_2O_5 ... several times	2×10^6 km^3
5.	From the rate of sedimentation	8.5×10^8 km^3

It is difficult to say which of these results may be considered most trustworthy. The last method certainly starts from the most definitely established figures, viz. the present rate of sedimentation. But the extrapolation over earlier periods with different climatic and physiographic conditions is open to doubt. Although the present author is inclined to believe that pelagic sedimentation is not open to such large variations as continental deposition, one cannot feel quite safe on this score. The third and fourth methods are definitely no more than checks that can only confirm the conclusions from other sources in a general way. It is gratifying in any case that no flat contradiction is encountered. The second method is capable of yielding fairly trustworthy results, but more accurate knowledge of the composition of continental sediments is needed. It is most improbable, however, that future corrections would bring alterations in the order of magnitude. The first method has the

advantage over the fifth of not involving much in the way of extrapolation on major points. But the initial composition of the oceans is postulated as fresh without proof. Furthermore the sodium content of the deeply-buried oceanic sediments is a point on which we are not sufficiently informed. But here again a drastic change in the estimate is not probable. All the corrections added by Kuenen amounted only to trebling the amount deduced by Clarke. Concerning the sodium method it appears to the present writer that the extrapolation—involved in the use of present pelagic sedimentation—to early periods even beyond the Cambrian is amply justified.

In conclusion, the total mass of deep-sea deposits is estimated at six to eight times 10^8 km.^{3} The thickness of the strata on the ocean floor must be between 1 and 5 km., most probably around 3 km.

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KAME-COMPLEXES AND PERFORATION DEPOSITS

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ABSTRACT: The plural "kames" implies a singular "kame"; but, since "an assemblage of kames" is a unit formation, it would make for clarity if it were recognized as such under the name of *kame-complex*. Many of the single, unattached mounds, frequently called *"isolated kames,"* have had a unique origin; and for them a denotative term, *perforation deposits,* is proposed.

The probable mode of origin of these perforation deposits is discussed first, since they are sometimes one of the elements making up a kame-complex.

The several processes whose combined action produces one type of kame-complex (the kame-moraine) are stated; and an attempt is made to evaluate the relative importance of each process.

Other types of kame-complex await further study to determine their significance.

IN a discussion of deposits overlying the till of Scotland, James Geikie (1874) introduced into the literature of geology the word kame, a term that has been a prolific source of mischief. Being descriptive of form only, it was much too inclusive: any hillock of glacial materials might be called a kame irrespective of its content, structure or mode of origin.

Although any attempt to formulate a definition of the whole group is foredoomed to end in absurdity, "definitions" of kame and kames have been attempted; they still find place in dictionaries (1941) (1943). And, while in one textbook (Longwell, Knopf and Flint, 1939) the word appears but once (in the index: "see knoll"); in another (Emmons, Thiel, Stauffer and Allison, 1939) the circumstances under which "kames" are formed are not only stated but pictured. It is evident that: if the several origins of these heaps of glacial materials are to be inquired into profitably, it will be necessary either to discard Geikie's term altogether, or to clarify its meaning; for to proceed on the assumption that glacial knolls are all alike, and that a description of any one kind will stand as a description of all, is to commit an unpardonable extrapolation.

Let us first, then, attempt clarification.

The word *kame* is a variant of coomb or comb; and just how the people of Scotland and the north of England happened to be using it when it was taken into the terminology of

geology, is beside the point—even supposing James Geikie understood the current usage correctly. A strictly etymological approach to the problem, such as that made by J. W. Gregory (1912), yields meagre results (and those misleading). Back of words are concepts, *i.e. pictures* that the speaker or writer hopes to convey *in their entireties;* but the modifications undergone by concepts are many and varied (extension, intention, transfer, etc.) and, even in living speech, we recognize "meanings" that are tropical, figurative, secondary and derived. In other languages of the Indo-European group the words most closely related to coomb signify a molar tooth, and (by extension) anything suggestive of the crown of a molar tooth. Different words were used for pointed teeth; and the ridge-and-hollow character of a molar crown was evidently familiar enough to serve as the sign for a concept whose underlying significance can be well enough expressed by an undulatory wave of the hand.

No single hillock is sufficiently suggestive of this progressive up-and-down-ness to have justified its being denoted by the primitive word-symbol, a symbol that has been used to denote: a serrate skyline, the comb of a barnyard cock, the wards of a key and (among adjectives) the quality: crooked. Yet, though it would hardly be applied to a single hillock, it could have been applied, in all appropriateness, to any *area of sag-and-swell topography* such as was called by Geikie "an assemblage of kames."

Now, whether or not the testimony of philology is reliable, it is too late to ask that "an assemblage of kames" be hereafter known as "a kame" or "a coomb"; so, in the discussion to follow, we shall call such an "assemblage," a kame-complex, with the understanding that a complex is a unified whole, and in no sense an association of discrete units.

Another type of hillock recognized by the same author, is the "isolated, solitary mound." Geikie avoids using the term kame for such hills: he calls them merely mounds, cones or conical hills; and, while a common origin for all solitary mounds cannot be taken for granted, certain of them have been formed by the collapse of columnar masses of detritus and may be grouped together under the name *perforation deposits.*

A considerable number referable to this class has been found, of which three conical examples had been opened from peak

to base, exhibiting a structure which demands for its explanation: a cavity or vertical shaft through the glacier, of unknown depth and *without any outlet for water at the bottom.* The cores are composed of cross-bedded sand with a high-angle dip as though spilled in from a height; and these beds are covered by an enveloping layer in which the dips are predominantly parallel to the sides of the cores, as though, after deposition of the latter, more sand had fallen down over the apex. Fifteen years ago the writer failed to appreciate fully the significance of these solitary conical hills (Cook, 1930): it was recognized that they were deposits made at the bottom of ice-shafts (probably, it was thought, abandoned moulins) but why the fill did not run on into an (assumed) outlet-tunnel remained a mystery.

It now appears that there are in stagnant glacial ice such things as vertical shafts that are not moulins, and that have no bottom outlets. They are today being gradually deepened in the stagnated termini and piedmont expansions of glaciers wherever an insulating blanket of detritus has, for any reason, accumulated on the surface of the ice. Eventually, it may be presumed, they will perforate their glaciers and permit the detritus to fall to the basement. Described in 1891 by Russell (1891), they were given a somewhat fuller treatment in 1902 by W. O. Crosby (1902); and the manner of their formation can be inferred from a recent paper by the writer (1946).

The temperature of meltwater at 0° Cent. cannot be raised by contact with warmer air more than about 3.9° Cent. as long as it remains in contact with ice; and, because of the poor thermal conductivity of water, heat "absorbed" by a pool from warmer air, would remain at the surface for an indefinitely long time, were it not for the fact that, within this narrow range (0° to 3.9°), the water's density *increases* as its temperature *rises.* Just before the temperature reaches 4° Cent., the surface water sinks to the bottom and all its heat in excess of 0° Cent., is *expended in melting the ice.* When heating of the surface stops, the bottom water soon parts with its excess heat and the pool is again in thermal equilibrium with the ice.

Ordinarily, the ablation of ice exposed to the air (in which constant evaporation plays a large part) is so much more rapid than the slow process of melting below a water level, that the effects of the latter are negligible until the rate at which

ablation has been progressing is somehow checked. This occurs ordinarily when detritus accumulates on the glacier, as when a blanket of "ablation moraine" becomes thick enough to interfere seriously with evaporation. When this stage is reached, the penetrating shafts become notable features of any topography underlain by stagnant ice. They are necessarily full of water to the level of a (probably concealed) sill; and the lakelets appearing here and there in the midst of the covering of débris (Text Figs. 1 and 2) are often surprisingly deep. Crosby says that on the Malaspina glacier some have already attained a depth of "fifty to one hundred feet or more" (ref. p. 19).

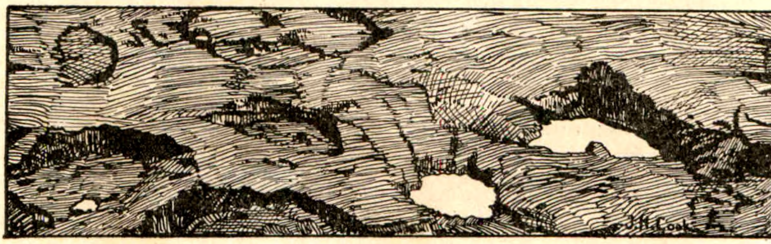

Fig. 1. The stagnant end of an Alaskan glacier (Chitina), covered with ablation moraine. Slow reduction of the ice-surface is causing the blanket of débris to settle into each more rapidly ablating area (outlined by arcuate bluffs). Several of these areas have deepened until the débris has been carried down out of sight in shafts now marked by pools. Eventually, these pools will perforate the glacier. *From a photograph by Bradford Washburn.*

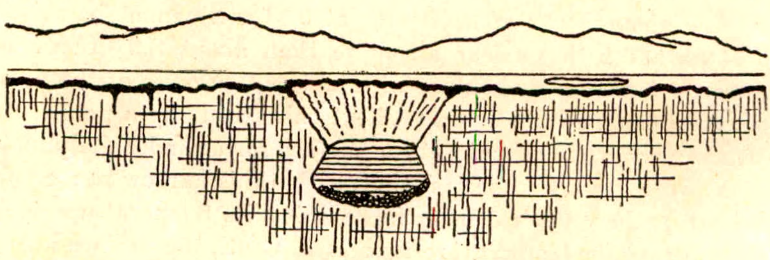

Fig. 2. Cross-section of a perforating basin and its contained detritus and water. The basin is deepened by heat absorbed at the surface of the pool and carried down as fast as the water's temperature is raised from 0° Cent. to its point of greatest density (about 3.9° Cent.). *After I. C. Russell.*

Masses of débris carried into a lakelet do not arrest the deepening of its basin, though they may affect the direction taken by the shaft; and insulation of the side walls is impos-

Plate 1. Perforation cone composed almost wholly of cobblestones. *From New York State Museum Bulletin No. 332.*

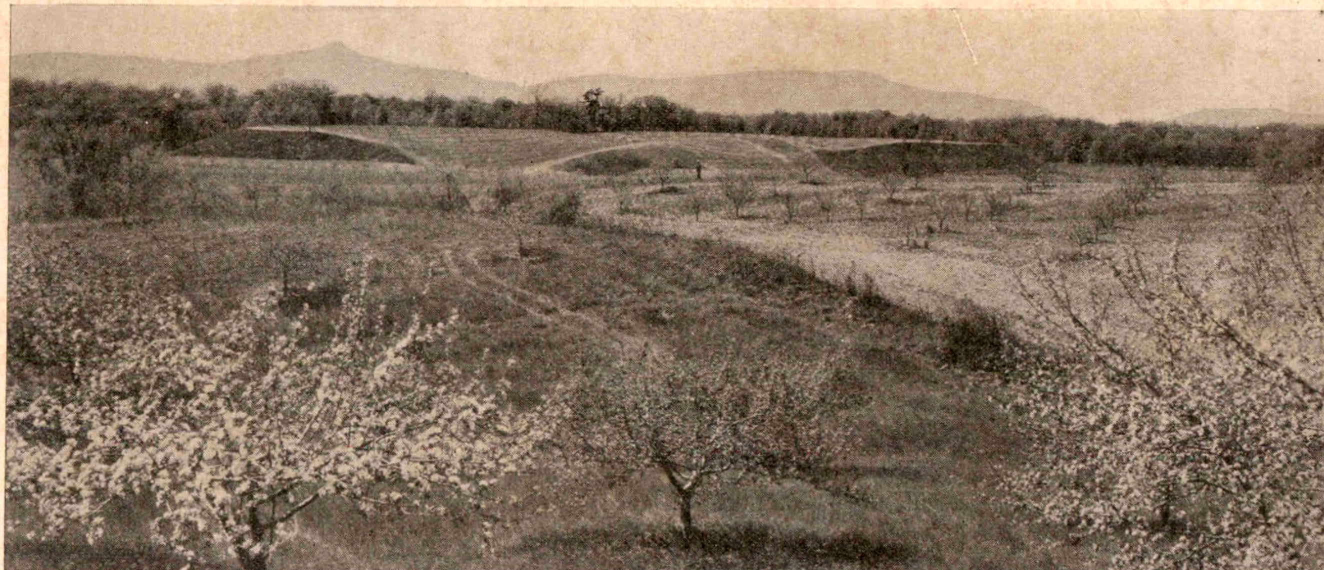

Plate 2. A cavity-filling (platform) of stratified sand. Where the whole glacier has become thin, the process that in thicker ice produces perforation basins, results in broader, shallower cavities whose form may be preserved by inwashed sediments. *From New York State Museum Bulletin No. 331.*

sible as long as the basin contains any water. A filling of cobblestones would offer little opposition to the vertical descent of heat-carrying water, while a layer of rock-flour or very fine sand, being an impenetrable barrier, would deflect its movement horizontally.

Presumably, the development of shafts may begin at any time until the glacier has been reduced locally to the final stages of dissipation; and those that are formed late are cavities* rather than shafts. When cavities are obliterated, as such, by sedimentary fillings, the fillings remain, after the ice has gone, as platforms. Besides the perfect cone (Plate 1) and the perfect platform (Plate 2) there are many irregular and compound forms that have had essentially the same origin, and whose containing basins were doubtless made in the same way.

We have, of course, in each case, the very last episode only from which to reconstruct a history that may not have been as brief as casual observation in the field would suggest.

These, then, are perforation deposits; and whether they are conical or not, they have nothing in common with "kames" as kames have been defined by lexicographers and writers of text-books.

We may now consider those deposits with which the floors of many Scottish valleys are cluttered, giving to them a billowy or rapidly undulating appearance: the "assemblages of kames" or, as we shall call them, coombs or kame-complexes. These occur most frequently, and are most typically developed "at or near where the rivers escape from the confined mountain-glens or upland dales to enter upon the broad low grounds" (Geikie, page 187) *i.e.* in situations where stagnant piedmont expansions might be expected to have melted out.

Since the discovery and exploration of the Alaskan glaciers, much has been learned about terminal "dead ends" and motionless piedmont expansions; and it is now generally recognized that increase in the rate at which ablation takes place (relative to alimentation) results in thinning; and that protracted thinning may result in terminal or peripheral stagnation. This paper deals with the final liquefaction and vaporization of such

* Whatever their shape, such cavities are not crevasses; and Salisbury's term "crevasse-filling" should be dropped.

stagnant bodies of ice; and the discussion that follows may be summarized by the statement that: should the present rate of melting continue until the stagnant, débris-covered marginal zone of one of the Alaskan glaciers is completely dissipated, there will remain a subdued kame-complex consisting largely of till. If, however, climatic conditions favoring the production of copious meltwater should overtake the dead terminus while some of the ice remains, there will result a kame-complex comparable in all respects to a Scottish coomb.

The first task, then, is to analyze the process by which such a stagnant marginal zone is reduced; and to determine, as far as may be possible, the relative efficacy of the several factors entering into that process.

The factors are: gravity, evaporation, perforation, surface melting, undermelting and bottom-melting. The term perforation may be applied to the melting out of cylindrical or irregular shafts as previously discussed; undermelting will be used to denote what is essentially the same thing but taking place in basins not completely walled by ice.

In the Antarctic regions, where comparatively little rock débris is being carried by the glaciers, and where the temperature seldom rises above 0° Cent., certain of the outlets from the great central ice-dome have been so reduced by evaporation alone that they have stagnated; and, in time, the stagnant remnants may be completely removed without ever having melted at all. Alimentation must exceed evaporation if a body of ice is to persist. When the temperature of the air bathing such a body rises above 0° Cent., the rate of evaporation is increased, and liquefaction becomes an *added* means for removing the ice.

The presence of englacial débris and superglacial moraines affect the rates of both evaporation and melting profoundly; and, because typical kame-complexes are often made up in large measure of such materials, it will be convenient to rehearse matter with which glacial geologists may be supposed to be thoroughly familiar. For nearly a century now, James D. Ford's explanation of the frontal dip of the veined structure at the end of a glacier (*i.e.* that it is due to basal ice "being forced upward by the action of frontal resistance") has been verified or rediscovered time and time again; and the conventional diagram used to illustrate it need not be repeated here. One

criticism of the diagram, however, should be made at this point: perhaps half a dozen bands of upthrust ground moraine are represented in longitudinal section; enough to illustrate the principle involved, but too few to suggest the circumstances attending formation of any but the smallest, most terminal-morainelike of kame-complexes. Since each upcurving line stands for a forward movement that failed against the dead nose, there should be no implication that the number of such feeble advances was limited to six; there may have been forty or a hundred.

Whatever the number of these exhibitions of waning power: if the "receding hemicycle" has set in, a day must arrive when the last one has been made. Either the position of the front of active ice withdraws from its dead nose gradually; or the section back of the nose also stagnates; so that, after an interval during which thinning takes place, it offers "frontal resistance" to a subsequent advance of the glacier *farther up-valley*. Since, however, a determination of the special manner in which the distal clean ice was removed is not of importance in the present discussion, we choose to fill out the picture by regarding that ice as inert. In either case it would disappear by evaporation (or, in warmer air, ablation) long before the drift-impregnated section from whose included till a kame-complex will be, in part, fashioned.

The melting down of this ice has been described by Prof. Richard F. Flint (1940), and by Prof. John L. Rich (1943); and, if there were nothing to add to these descriptions, there would be no point in repeating what has already appeared in print.

Before we undertake to evaluate the work of the several processes that eventually remove stagnant ice from under a protective cover of ablation moraine, it should be pointed out that the environments in which removal takes place are various; and, if we are to arrive at the general view that is our aim, many of the variant factors of which the reader will be aware must be touched upon lightly or ignored altogether. Among these variables there is one that must be taken into account, namely; the position of the "snow ceiling" or (atmospheric) isothermal layer of 32° Fahr. at the time when stagnation sets in, for the nearer this lies to the locus of kame-complex formation the less will meltwater enter into the picture. If it lies

close, valley trains, aprons and outwash plains may have a feeble development or none; if much higher, the moving ice will be far up-glacier because the same climatic conditions will not be conducive to both active ice and copious meltwater at one and the same time.

We will, then, assume an environment in which the snow ceiling is, at first, near the section of blanketed ice, but later moves to a relatively higher position. The earliest reduction will be due almost wholly to evaporation; and presently the drift content in the distal part begins to conceal the surface of the ice. Due to heat "absorbed by" and "reflected from" stony matter, this becomes pitted and, finally, almost impassably rough as general ablation lowers it to the point where accumulated débris retards melting and almost prevents further evaporation, except where the cover is thin. Meantime, the cleaner ice up-glacier continues to evaporate until its surface stands at a lower level than that of the ablation moraine. (It may even disappear while the protected section still stands like a great mound of dirt.) We may now consider the effects produced by elevating the snow ceiling. Air temperature will rise and, in consequence, liquefaction of the ice under the dirt-mound will become the *obvious* manner in which it is being reduced. An insulating blanket retards but does not prevent melting: so that the bottom of the ablation moraine is soon water-soaked, while every point where it is thin or absent becomes the site of a shallow basin destined to develop into a cylindrical or irregular shaft that, in time, will perforate the ice.

This much in the way of reduction may be accomplished without any modification due to the presence of lateral waters; and, if there is free run off of glacio-natant streams, the end product will be a type of kame-complex that is little more than a mass of till. Nearly all kame-complexes, however, are more than this; so, once more, we must consider the matter of environment: there may have been an inheritance of frontal moraine (push, dump or lodge) or of outwash; and, if so, meltwater may be ponded behind the obstruction, and undermelting of the ice at its base begins, efficient in proportion to the area of water-surface exposed to the air. Recesses, melted out of the basal ice, become deep pockets and blind tunnels; and, in spite of the slowness of underwater melting,

such tunnels may meet perforating shafts; broken off cornices may be afloat against the thicker, unlifted ice; and, in general, the separated glacier-remnant may be pretty well honeycombed and shattered before sediments arrive in quantities great enough to put a stop to melting below the water level, and to preserve the particular stage of local glacier-decay that has been reached. That most of this underwater decay is finished before sedimentation begins goes without saying: undisturbed sediments mean spaces which have been filled; and to be filled, the spaces must have been previously made.

What has happened thereafter, in any given case, can be determined only by studying the internal structure of the mass, a structure seldom sufficiently exposed to vindicate a casual judgment.

Some ice outlasted the deposition of those sediments out of which kame-terraces, platforms, and flat-topped stratified elements of the complex were built. Not only was it insulated by the surrounding or abutting sediments, but it was burdened, above water level, by whatever of ablation moraine had not slid or been rinsed off. The water table fell: the pools drained away; the last ton of ice melted; and the kame-complex was finished.

Nothing has been said about bottom-melting. Presumably, there was bottom-melting; and, in many instances, there was subglacial drainage through tunnels, parts of which tunnels became clogged with sand and gravel. The occurrence of a longitudinal ose or two running toward or into a kame-complex, early gave rise to the facile conclusion that the complex itself was vomited forth from the mouths of these tunnels, a conclusion that, in the absence of revealing sections, became almost an article of faith among glacial geologists. In the preceding paragraphs an alternative to this conception has been presented.

Thus far, we have considered only the Scottish type of kame-complex, the type that has been called kame-moraine, a term that is appropriate in that the accumulation marks an ice-front or margin, albeit a deserted and fossil position of such front. But to assume that, because the kame-moraine is a marginal formation, every kame-complex must be a kame-moraine indicating an ice-edge (in interpretations of Pleistocene continental glaciers: *the* ice-edge), is to overlook the possibility

of different origins for these mounded deposits. The external form known as kame-kettle topography is not infrequently merely a cast in stratified sand of floating masses of ice. Kame-complexes of this character were doubtless built by the incursion of sediments into water-filled basins that had not developed beyond the incipient stage: had the basins been somewhat larger or freer from floating ice when their development was arrested, it might be easier to recognize an affinity between the deposits that filled them and terraces or platforms. Although aware that there were many kame-complexes "disposed without evident relationship to [other ?] glacial phenomena," and, although recognizing that the morainic phenomena of eastern New York were obscure and feebly developed, T. C. Chamberlin (1883) deliberately chose to identify as kame-moraines certain of the valley-bottom terrace-accumulations of the Susquehanna drainage system, and mapped them (ref. Plate XXXIII) as indicating frontal positions of the diminishing Wisconsin ice-sheet.

That so eminent a student of glaciology could be misled by a predilection for interpreting in a particular way (ref. p. 376) deposits mounded and kettled by association with masses of ice, is our justification for holding that there are probably many kame-complexes the significance of which we have not as yet learned to appreciate; at any rate, they do not fall readily into the categories that have been discussed in this paper. Certain of these we hope to describe in a future article.

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DISCUSSION.

Cambrian and Ordovician Geology of the Catskill Quadrangle (*N. Y.*); by Dr. Rudolf Ruedemann. Bulletin 331, New York State Museum, Albany. "December 1942." (Actual publication in 1946.)—The Geology of the Catskill area, most concentrated and most visited of any in the East, has finally attained publication. New York State Museum bulletins 331 and 336 are off the press and with bulletin 307 give a fairly complete introduction to the whole Catskill region, whose bedrocks range from lowest Cambrian well into the upper Devonian in age. Part I, by Doctor Ruedemann, is here reviewed.

In this bulletin, the magic touch of a master hand has again resolved a wilderness of "Hudson River" beds into an orderly sequence of Cambrian, Canadian, and Ordovician formations and some new and startling conclusions are set forth. Here, as elsewhere north and south, the old Hudson River Group that was placed above the Utica turns out to be older even than the Trenton, in no way correlative with the Lorraine and "Frankfort" (a facies term) of farther west. Thus the situation in the Eopaleozoic of New York remains comparable to that in its higher Devonian strata. Facies correlations put together older beds at east with later ones at west. Only careful tracing and fossil collecting have been able to overturn these older views.

The study of this area (from Hudson to Annandale and Elizaville) has simplified the Cambrian succession as determined around Troy and amplified that of the Ordovician. The formations here recognized for mapping are (oldest at bottom):

Rysedorph polymict limestone conglomerate
Austin's Glen (upper Normanskill) shales and grits
Mount Merino (lower Normanskill) shales and cherts
Deepkill shales and cherts
(Break; middle and upper Cambrian missing)
Schodack shales and limestones
Burden iron ore (Bomoseen olive grit)
Nassau shales and quarzites.

The Bomoseen and assertedly equivalent Burden ore are mapped with the Schodack, which has been expanded to embrace also the Troy shales and limy quartzites as well as the (interbedded) Burden limestone conglomerate and Zion Hill ferruginous quartzite, formerly separately described in areas at north.

For the Nassau beds a possible late Precambrian age is mooted (pages 42, 61-62), partly through correlation with the Random terrane (page 60) of Newfoundland, and partly through the surmise that the Burden iron ore and other similarly situated ores over a wide area may be the erosional concentrates of the "Lipalian interval." But there is also (page 61) correlation of Nassau with the Hardyston quartzite of New Jersey which carries Olenellus; and there is, further (page 66), acknowledgment that the much higher Zion Hill iron-bearing bed marks "a reappearance" of the conditions that produced the Burden, both of these being included as lentils in the enlarged Schodack formation (compare figure 66). The reference to the Brayman (eastern Camillus) shale as a "regolith" (page 62) lacks support by other investigators. It is puzzling to read (page 88) that "most of" the five divisions of the Nassau are recognizable in the quadrangle, but (page 41) that "only a small portion," the "uppermost division E," is exposed.

In the Schodack formation are now recognized (pages 77, 67) at least two limestone conglomerates, the familiar Burden conglomerate of Grabau, low in the formation, another mistaken by Grabau for that but much higher in the Schodack, which may be called the *Claverack* conglomerate (type at Ham's Mills), possibly a third lying above the Zion Hill quartzite beyond the quadrangle limits. Doctor Ruedemann has not entertained the question as to whether the topmost beds here may be later than Schodack, possibly Upper Cambrian (compare pages 179-180).

The Ordovician beds are wholly clastics, representing (with the Cambrian) the complete section of the overthrust sequence except that the Schaghticoke shale has failed of recognition. A clean-cut separation has now been made between the lower and upper Normanskill, and the correct superposition of these beds has been determined—the part with interbedded grits (graywacke) being the upper and more western member. As to the boundary between the main outcrop belts of these two divisions of the Normanskill the engraved (colored) map differs greatly from the preliminary map (page 98) of 1936. Effort has been made to determine the thicknesses of these greatly mashed formations. At Austin's Glen on the Cats Kill (no resident knows this place by the map-maker's name "Austin Glen"), an outcrop of 355 feet across the strike (page 102) may much exceed the actual thickness here exposed, but the total thickness of this upper member is likely to be several times the estimate (page 107) of 500 feet (minimum), as the author himself suspects (page 88). The locality (pages 102, 104, 105) called "South Catskill" is West Catskill and the Post and Smith quarry is (pages 98, 102, 105, 115) at Broome Street (page 104) in a nose of what is locally called "Broomstick Hill."

The lower Normanskill, carrying interbedded radiolarian chert instead of grits, is referred to depths of over two miles for its place of deposition, the arguments for this being ably marshalled (pages 90, 101, 171, 174, 180; see also Ruedemann, 1942: bulletin 327—pp. 53-56) but so tied in with the "trough" theory (see beyond) as not to be wholly convincing. Similar cherts are reported (pages 84, 87, 94, 95) from the Deepkill shale associated (pages 80-83) with limestones and terrigenous quartzites of littoral type, hard to reconcile with "abyssal" conditions.

Two exposures of polymict limestone conglomerate are identified with the Rysedorph conglomerate of farther north (pages 87, 116-124, 180; pronunciation not indicated). The outcrop north of Elizaville (pages 123-125; see 120) carries pebbles with "Trenton" fossils, like type Rysedorph, but lies in contact with *Lower* Normanskill (Mount Merino) on both sides, only the west one of which is mapped as a faulted contact. It "covers an amazing area," with marginal dips of 45° and 60°, so that even if it is a "flat, overturned anticline" the thickness present must be very unusual. The other exposure, south of Mount Merino, without fossils but with pebbles of Lowville aspect and of chert, is veneered upon and involved in greenish shales necessarily either Deepkill or Mount Merino beds (the Austin's Glen has only gray to black shales), which two are the only formations mapped at this point, though "Normanskill grit" is said to occur "on both sides." These Trenton conglomerates, later in age than the shales and wholly exotic to them, furnish the most elusive problem (see beyond) in the entire Hudson River Ordovician belt. Certainly the evidence here is not that they lie in normal succession on the Normanskill (Austin's Glen member). Rather, they seem unconformable on various parts of the overthrust sequence.

The Becraft's Mountain outlier of Silurian and Devonian rocks was laid as a waif on Doctor Ruedemann's doorstep with suggestion that he could take over unrevised the published map and report by Doctor A. W. Grabau (1903). In so doing (pages 124-132), he has made two notable contributions, finding remnants (in occasional pre-Silurian depressions) of the iron-stained sandy Rondout beds (pages 10, 15, 126, 127, 131) like those at the nearest exposures west of the Hudson (see figure 11 of bulletin 336), and convincing proof of the great unconformity (pages 10, 15, 124, 127, 149, 168) at the level which he so aptly calls (page 10) a "fossil peneplain." Welcome also is the criticism of so many normal faults drawn on the Grabau map (page 132); although bringing this outlier struc-

turally into line with the western embed[1] may void the writer's hypothesis (bulletin 336—p. 230) of its ride upon the Taconic overthrust. Seemingly (see beyond), contrary to the remark on page 139, "Logan's" thrust passes directly under the mountain (figure 55) without visible effect upon it.

A slight error in names is noted. Although his map elements are the same as mine (bulletin 336), the combined Coeymans-Kalkberg is called simply "Coeymans" (pages 127-128) with the Kalkberg stated to be a member of that instead of part of the New Scotland (compare correct usage by Goldring in bulletin 332—p. 159; and by Ruedemann in bulletin 285—p.49). His "New Scotland" is only the Catskill shaly member of that formation. Thus the Coeymans-New Scotland boundary is made transitional (page 132), which is true of the Kalkberg-Catskill within the New Scotland, whereas the real division (Coeymans-Kalkberg) is the sharpest stratum-plane in the Helderbergian (see also beyond).

Since Alsen is basal Port Ewen as truly as Kalkberg is basal New Scotland, and is included in the 222 feet at Rondout, Grabau (page 129) was not mistaken. But absence of the shaly main Port Ewen here as on the west emphasizes the large sub-Oriskany break unmentioned in this report. The suggested break (page 131) between Rondout and Manlius must, however, have been very small.

Structural relations (pages 131-157), are most delightfully described, aided by picture and diagram. Especially novel is the matter on "boudinage" (pages 150-157) in the quartzite interlaminae of the Nassau slates, definitely proving "take-up" of compression by a general squeezing of the mass (compare bottom of page 145 and figure 51) rather than by plication as in the less metamorphic belt farther west (page 141; contrast figures 56-60 with 53, 54).

The "troughs" and "barriers" here interwoven (pages 37, 78, 135-137, 172-175, 176) will be considered beyond under history, but the evidence of overthrusting is convincing (pages 139-142) without recourse to these. The Coxsackie quadrangle map (bulletin 332) does not seem, however, to terminate "Logan's Line" (page 138) in the Hudson River (page 139) at Poolsburg opposite New Baltimore, but picks it up again for over two miles past Stuyvesant and resumes it (Nassau over Normanskill) at North Bay, Hudson, joining it to the fault on the Catskill sheet that passes under Becraft's Mountain (see pages 141-142) but which is inadvertently shown in diagram (page 149) as a low angle normal fault. The

[1] Note (by request). "Embed" (em'-bed), supposedly long current but not found in the dictionaries, is taken to mean the main mass (not simply the outcrop) of a given rock in situ as distinguished from transported blocks and perhaps from small outliers.

fault on east of Mt. Merino (same page) is also shown as normal, and is so described (page 142), but this likewise does not agree with the (colored) map.

The real Logan's Line is probably not this one at all but runs between the west edge of the Normanskill and the Snake Hill beds, and is here buried beneath the western embed of the Silurian and Devonian. That it is not between the Snake Hill and Canajoharie was already admitted (pages 187-188) in Ruedemann, 1930. These lesser thrusts separate the nappes (page 141) of the "shingle block" structure (page 188), do not bring distinct facies into juxtaposition, and probably lack such breadth of geographic translation (15 miles) as would be called for by the engaging theory (pages 50, 141) that the iron-ore belt has been torn out of the Harlem valley. The answer to the "moot question" (page 146) whether folding or thrusting accounts for the presence here of this iron-ore belt and of the "bird-shaper inlier" in Germantown is not in the asserted sundering of upper and lower Normanskill belts by these bodies, which is not sustained by either the older map (page 98) or the final map that as already noted differs so much from the older map, nevertheless both folds and faults are sufficiently evident in the maps (compare figures 21, 51, 55, 66). The final map does not agree with the text (page 145) as to the bounding faults of the Germantown inlier.

The historical interpretation (pages 171 to end), opening with a readable and enlightening discussion of geosynclines, proceeds to postulate subdivision of the St. Lawrence geosyncline into three "troughs" in which Eopaleozoic sedimentation went on independently and largely alternately (pages 186-188 quoted from 1930, and 172-176; see also 87, 78), a thesis long advanced in the bulletins on this general area for two such troughs. To these Doctor Ruedemann now adds a third for the eastern (or carbonate) sequence of Prindle and Knopf (1932), overlooking that this is the resident sequence (autochthone) and is overthrusted from the east by their Taconic sequence (his former eastern), a conclusion inevitable from the mapped field relations such as (their pages 293-294) fossiliferous Lower Cambrian overriding fossiliferous Lower Ordovician near Hoosick. Yet he is evidently (page 174 and diagram in Ruedemann, 1942: bulletin 327—p. 57) veering away from a theory that admittedly presents certain difficulties. One of these, not remarked by him (but by Kay, 1937—p. 272-273), is the source and route of the terrigenous sediments. Another is lack of any trace today in the overthrusted masses (pages 187, 173) of the hypothetical barriers (page 176; Precambrian rocks, in bulletin 285—figure 8). These have disappeared from the 1942 diagram, just mentioned, as has also the predicated alternation in the

separate troughs (compare figure 50, page 136, and "one general basin," page 180).

First to recognize facies changes (Dolgeville shale) in our Eopaleozoic rocks and extending such observations at length throughout the Mohawk valley, and also early to grasp the frequency and extent of overthrusting at the east, Doctor Ruedemann yet hesitates at the final step of original direct continuity of deposition across all the fault sequences, surely only because of having them in the wrong order, 1-3-2 as now instead of 1-2-3 as originally. An unpublished continuous section from Watertown via Utica to Albany drawn by me accurately to scale in 1935 shows the facial behavior of the Ordovician to follow closely the laws and pattern that govern in the upper Devonian (compare Holzwasser, 1926—p. 53), and as early as 1925 I pointed out to others (ibidem—p. 63; Kay, 1937—p. 272) the identity of the Snake Hill as a facies of the Canajoharie, thus not of a separate trough. Ruling out imagined abyssal depths for the cherts, one sees only normal coastal plain sedimentation from western Massachusetts to Lake Ontario, with the correlations shown in the accompanying table.

To locate a geosyncline in Massachusetts and shift it "after contraction" (page 172, compare 161-164) to eastern New York, albeit it looks that way on the Schuchert (1930) maps, as though the states remained stationary while the geosyncline slid over them, may be rather misleading but is the fault of using maps that are not palinspastic (Kay, 1935).

In the list of neighboring Precambrian outcrops (page 175), our nearest one, Stissing Mountain, has been left out.

What now becomes the really engaging problem is the unmentioned one of the Trenton limestone conglomerates, whose pebbles definitely derive from the resident sequence but whose present seat is on the overthrust slice, on rocks that in Trenton time lay presumably 100 miles farther east than now (Kay, 1937—pl. 5). Moreover it appears that these conglomerates rest not only upon the top of the Normanskill (Austin's Glen) as the last deposit in the area preceding the overthrust but also on the lower Normanskill (Mount Merino) and possibly even on the still lower Deepkill, as already mentioned. Since the matrix of the conglomerate itself is dated by early Trenton fossils, being clearly not a fault-breccia, can the translated block have suffered a large part of its present dislocation at the close of Normanskill (Black River) time coincident with the volcanic activity and marked break in sedimentation found by Kay (1937—pl. 2 and fig. 9) and been eroded down to the Deepkill on higher folds in Sherman Fall time? These are alarming suggestions, but not lightly to be disregarded in view of the similarly transgres-

Tentative Correlations
in Cambrian through Ordovician
of Eastern New York.

AGES	The Capital District Albany and Troy Quads.		Dutchess County	Taconic Quadrangle	Overthrust Blocks Logan's, Greylock
	Silurian capping		O	O	Silurian
UTICA	Indian Ladder	O	Overthrust by argillaceous rocks of the Taconic sequence including Nassau shale and probably younger beds.	Overthrust by argillaceous rocks of the Taconic sequence	(Lost by erosion)
TRENTON	Schenectady				
	Canajoharie	Snake Hill			
	Glens Falls	?Rysedorph			?Rysedorph
BLACK RIVER	*Amsterdam*			Walloomsac	Austin's Glen
CHAZY	*Chazy* (to north)			*Calcitic limestone and marble.*	Mount Merino
CANADIAN	*Beekmantown* (to north)		*Rochdale*		Deepkill
OZARKIAN	*Little Falls* *Theresa* (*Hoyt*)		*"Hoyt dolomite"*		Schaghticoke ?
UPPER CAMBRIAN	Potsdam (from north)		?	O	O
MIDDLE CAMBRIAN	o		o	o	o
LOWER CAMBRIAN	o		*Stissing*	*Rutland*	Eagle Bridge *Schodack* Mettawee Hoosac Bomoseen Rowe
	o		Poughquag	Cheshire	Nassau ?Rensselaer
	Precambrian basement				? (Overthrust)

NOTES: O means re-eroded; o, not deposited. *Calcareous facies in italics.* Kay (1937—p. 272-273) refers Snake Hill to the western sequence. He likewise refers the Rysedorph polymict limestone conglomerate to the western sequence (page 277), stating that Ruedemann described it as interbedded in Snake Hill, which description I do not find. Its relations are always with the Normanskill, of the overthrust mass.

sive relations of the coeval Lacolle conglomerate (Kay 1937—p. 275-277) and the sudden westward shift of clastic sediments after Glens Falls limestone deposition.

The delayed decision to print the Catskill report as two bulletins obliged Doctor Ruedemann to include Silurian and Devonian history (note reference to "Part 2" in Contents, on front cover). Faced with this necessity he turned naturally to his Capital District bulletin (No. 285), with minor omissions lifting this bodily.

Unfortunately this fits not well in spots (Oriskany, and Schoharie), and in the fifteen years revolutionary changes have taken

place in Upper Devonian correlations, Silurian and Devonian paleogeography, and other details. No longer do the seaways of those times run as Doctor Schuchert pioneered them, the New Jersey gateway is delta-filled, the Albany bay proves a figment of Grabau's "Sherburne bar," true Portage rocks fail to kiss the Catskill summits in our map area. Clarke's theory of lower Marcellus becoming top Onondaga westward has misfired, but all of our "Marcellus" (Bakoven) seems only the partly calcareous basal part (Union Springs) of central New York while it is our "Hamilton" that is the bulk of the Marcellus, the true Hamilton being here the original Catskill (Kiskatom) redbeds that Prosser mistook for "Oneonta." There are small slips—Salina following Rondout (page 181: compare bulletin 285—p. 172), an eastern source for the Manlius sea (page 182), "transition" beds from Manlius to Coeymans which are reworked Manlius marking an extensive erosional break (bulletin 336—p. 152; note qualifications in bulletin 285—p. 47, 173, here omitted), the Coeymans-New Scotland "transition" previously noted, the "well-set-off" Becraft (page 182) where there is indeed a troublesome gradation and interfingering (Grabau, 1903—p. 1062) here and all up and down the Appalachians (see Woodward's Devonian of West Virginia—p. 83, 95-97), inapplicability of the "turbulent sea" of the Oriskany sand (page 183) to our thin beds of (Glenerie) chert and silicious limestone with their frail fossils, and of the "sandy facies" of the "Schoharie" (Saugerties formation or "Leeds member") hereabouts (compare page 180). The discussion of the higher Devonian strata (pages 184-186) follows the wholly erroneous work of Prosser (see bulletin 336—p. 116, 125, 137). The "enormous amount of material" (page 186) that must have been removed above present exposures was the higher Upper Devonian (Catawissa, Montrose, Blossburg and other successively later redbeds), probably no Pennsylvanian and definitely no Mississippian strata.

Discussing the orogenic history (pages 160-170), Doctor Ruedemann analyzes (167-170) various age criteria worth careful attention, but (page 168) misinterprets Schuchert's maps (1930—figures 1 and 2, not "4" and "5") in saying that the second "clearly indicates the middle Hudson River region was only folded by the Taconian and Appalachian orogenies;" whereas that figure (65 of the bulletin) shows only "present location of geosynclines" that (Schuchert, page 706) "in late Devonian time" were wholly "blotted out by the Acadian disturbance," and the map shows that this includes our area, while Schuchert's figure 4, that does map the orogenies, likewise carries the belt of Acadian folding south across our quadrangle with proper strike to "at least Newburgh" (his page 722), but gives an easterly direction to the Appalachian belt past

Kingston. Doctor Ruedemann recognizes (page 161), however, that the "Appalachian" or "Carboniferous" folds (pages 17, 139) may prove to be Acadian (compare bulletin 336—p. 227-230). But whether the eastwardly increasing metamorphism, with westward overthrusting of the less folded metamorphosed nappes (pages 141, 145), is Taconian, Acadian, or Appalachian, is another question not yet answered.

The subsequent history involves the controverted origin of the present drainage pattern (pages 22-26), presented with great fairness but without reference to important papers by Fairchild, Mackin and others. That the parallel west-southwest courses of the upper Susquehanna and the two Delawares (figure 7) were consequent on the dip slope does not agree with a known original (depositional) dip to west-*north*west, or with the oldest recognizable (mountain summit) peneplain (Guyot 1880) which slopes northwest; neither is it a case of structural control by anticlines (Hall, 1876; see bulletin 307—p. 35, 51, 68, 83) that have proved non-existent but still plague the literature on this subject (Strahler, 1945—p. 68). As the present regional dip here is east of south, these streams run nearly on the strike; and this regional dip into the geosyncline must date from Appalachian orogeny. It is more likely that the streams were controlled at first by parallel receding escarpments, and later rapidly intrenched. We must disagree also with carrying the Hudson River back to Cretaceous time (page 24), because the two branches of the "Cretaceous" Schoharie Kill plainly headed far east across the present Hudson Valley.

The physiography resultant from the long periods of erosion is treated with great clearness (pages 6-26) except for one matter—the Helderberg plateau which is a strata-controlled feature (figure 1, so retouched as to be worthless for evidence, and page 8) is confused with the Helderberg peneplain (figure 8 and pages 9-10) which is beveled across the strata and does not decline southward with them. The peneplain is continuous with the mature valleys extending from the north into the Catskill Mountains monadnock area and lacks representation under the east lea of the mountains. Its eastward counterpart would be in the Taconic Mountains, not in the much lower phyllite plateau whose existence seems to be purely a matter of differential hardnesses, not of erosional base-level. Throughout our quadrangles the Helderberg "plateau" has fallen to the level of the Hudson Valley (Albany) peneplain, which here reaches to the east foot of the Catskills.

The statement that the strike of the Eopaleozoic rocks (pages 13, 17) has a northeast skew, while true of the overlying Devonian ones, is not borne out by either the geologic or topographic map except for Mount Merino, nor is it true that the main glacial move-

ment was due south and responsible for the north strike of the ridges. The ice flow was definitely west of south, diagonal to these minor ridges but parallel to the great mural front of the Catskills, the edge of the phyllite plateau, and the course of the Taconic Mountains (western boundary of Massachusetts). In fact, this north strike of the Ordovician grits as they pass under the northeasterly striking scarp-front of the Silurian-Devonian limestones is one of the striking evidences of their unconformability, and distinguishes Taconian from Acadian folding.

The strange behavior of the Hudson tributaries on the east, which is duplicated on the west by that of the Kaaters Kill and Esopus (figure 8 and pages 24-26), is brought out but its explanation left to Professor Cook's glacial chapter, which is not here under review. See bulletin 336—p. 214-218.

Concerning the interesting suggestion that grade-plains are beaver work (pages 21, 26) one is inclined to ask which came first—the beavers, or the graded surface that enticed them by permitting broad shallow impoundment by dams. The conical hill east of Blue Stores (page 18; compare 199, bottom) called a drumlin has a gravel-pit (contoured) in the west base and was considered to be a kame by Doctor Fairchild, (see bulletin 336—p. 192).

The chapters on botany, zoology and economic geology (pages 26-30, 239-242) projected by me for the combined report have, to equalize space, been placed in Part I, that on minerals wholly omitted. In the list of trees, taken from Doctor Bray, one is astonished to find such southern species as the pawpaw, cucumber tree and coffee tree, none of which I have seen here, and also the redbud as native and the hackberry as abundant (page 28). The cactus colony at Saugerties (page 30) is due north instead of northwest of the railway station.

It is unfortunate that the intention to issue the combined maps with each part, as indicated by the caption on the map pocket, was abandoned, the maps printed separately. Still more regrettable from the standpoint of scientific accuracy and priority, is the dating as of December, 1942, a contribution to knowledge not off the press until February, 1943, and not yet distributed to the world in January of 1946. Every copy should be stamped with the date of actual release of this edition.

Besides evident misprints for Mastigograptus, Whitfieldella, Pterinea, Dodecatheon, occidentalis, Bell Pond, Plass Hill, Stafford, and more common words, there are Alexander for Alander, Greenfield for Greendale, gravity folds for gravity faults, and Malden (page 36) for Cementon: but more misleading is non-sense caused by editorial deletion of commas (note pages 9, 127, 145, 173, 176, 188) without regard to author's wishes. One misses a measure of

size in several figures and is left uncertain as to whether figure 30 shows Deepkill or (page 94) Mount Merino chert, whether figure 48 looks north when the river lies on that side of the track (see map) and whether this is not a syncline instead of an anticline; whether, on page 89, "homotaxial" (similar in order) or synchronous is intended; whether it is the Green Mountain range (page 175) or the Taconic that borders Massachusetts; and how a trough (page 180) can fill with thousands of feet of land-wash while its feeding slopes on both sides are lined unbrokenly with pure limestone accumulating. The limestone at Stissing Mountain (page 179) is now said to be Lower not Middle Cambrian. Since Coeymans is not a possessive but the family name of Barrent Pieterse Coeymans who owned the site of the present village, the right spelling of the Sieberella would seem to be coeymansensis, not "coeymanensis."

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SCIENTIFIC INTELLIGENCE

PHYSICS.

The Electron Microscope; by E. F. BURTON and W. H. KOHL. Pp. 325. New York, 1946 (Reinhold Publishing Co. $4.00).—Revised and enlarged edition of an authoritative book on a fascinating young subject. Much of the material has been completely re-written. New plates are added and an extensive bibliography is appended. HENRY MARGENAU.

Principles of Physics II. Electricity and Magnetism; by FRANCIS WESTERN SEARS. Pp. 1-484; profusely illustrated. Cambridge Mass., 1946 (Addison-Wesley Press, $5.00). *Principles of Physics III. Optics*; by FRANCIS WESTON SEARS. Pp. 1-323; profusely illustrated. Cambridge, Mass., 1945 (The Addison-Wesley Press, $4.00).—The first volume of this series (see AMER. JOUR. SCI., Vol. 242, 568, 1944) raised the hopes of teachers who were dissatisfied with the superficial introductory physics course now taught in most American colleges. It set a high standard of quality, a standard which has been maintained if not even raised in volumes II and III.

The series of three volumes covers the traditional material of an elementary physics course, but with a degree of thoroughness and comprehensiveness that requires two years for its teaching. As the author explains, the first volume is used during the first year, the second is the basis for 2/3 of a second year course which is concluded with the last volume.

It is the purpose of this review to appraise the books, not this teaching arrangement. Nevertheless it is difficult, in reading the series, to suppress a growing enthusiasm for the arrangement. If a two year course in physics permits the virtues amply displayed in these volumes to be incorporated into the teaching, then by all means let us have two year elementary courses for science majors. The books are effective advertisements for this point of view.

As to the last two volumes, they are made particularly attractive by an inclusion of an abundance of good and clear line drawings as well as attractive photographs. Greatest care has been used in their selection and execution in connection with the treatment of optics, where clear diagrams are essential.

This reviewer, who regrets to have no opportunity to teach a thorough two year course based on the series, nevertheless values it as a source of collateral information for the better students in sophomore physics. HENRY MARGENAU.

CHEMISTRY.

Physical Methods of Organic Chemistry, Vol. I, edited by A. WEISSBERGER. Pp. vii, 736, adequately illustrated. New York 1945 (Interscience Publishers, Inc., $8.50)—This is the first volume in a series bearing the title "Technique of Organic Chemistry." In the Preface the Editor says "The chemist, in order to acquaint himself with a certain physical method, has in the past been compelled to search through periodicals and specialized books. The present work has been compiled with the hope of relieving him of much of this burden. It has been the object of the authors to provide a description of tested methods, the theoretical background for understanding and handling them, and the information necessary for a critical evaluation of the experimental results." In the opinion of this Reviewer this object has been well met. This first volume (there will be a second on Physical Methods) deals with the following topics, the Author's names being given in parentheses: determination of melting and freezing temperatures (Skau and Wakeham); determination of boiling and condensation temperatures (Swietoslawski); determination of density (Bauer); determination of solubility (R. D. and M. J. Vold); determination of viscosity (Mark); determination of surface and interfacial tension (Harkins); parachor (Thomson); determination of properties of monolayers and duplex films (Harkins); determination of osmotic pressure (Wagner); determination of diffusivity (Geddes); calorimetry (Sturtevant); microscopy (Jelley); determination of crystal form (Peacock); crystallochemical analysis (Donnay); x-ray diffraction (Fankuchen); electron diffraction (Brockway); and refractometry (Bauer and Fajans). This volume has no index, but a detailed subject index is promised in Volume II covering both volumes. Each chapter is preceded by an outline of its contents, with page numbers, which serves to some extent as an index. Any reviewer of a book such as this is bound to find places where he disagrees in some way with the author's treatments or lack of treatments of certain topics. Thus Hauser, (in J. Am. Chem. Soc. **67**, 2278 (1945)) finds several chapters which "call for amplification and in some instances for a reduction in personal opinions of the author—" and Westheimer (in Ind. Eng. Chem. News Ed. **24**, 100-101 (1946)) appears to find an insufficiency of specific examples of applications of the methods to problems which would directly interest the organic chemist. The Reviewer feels that the personal opinions of the authors are to be desired, when the authors are experts in their fields, and that with the ample references given the reader can seek amplification of any of the subjects with a minimum of effort. Actual omissions are another matter, though here, again, the question may be one of

opinion. Thus the Reviewer would have liked to see some reference in the first chapter to the important work of Fredga and his associates on the use of temperature-composition curves to determine the optical configuration of not too unrelated compounds.

However, a volume such as this is not designed to be a compendium. This one should be exceedingly useful to the practicing organic chemist because of the detailed critical descriptions of methods and theory given. It could be read with profit by the student of organic chemistry who is preparing for his comprehensive examinations, and it should be helpful to those students and others who in the last few years have been drawn away from chemistry into other pursuits and who now are returning to their studies and need to get back into the "feel" of chemistry and its methods of research.

As far as the Reviewer could observe the book is relatively free from errors and misprints; only 13 were noticed, and of these 10 were in the work of a single author. The book is very adequately illustrated with line drawings and photographs. It is well bound and presents a pleasing appearance. HAROLD G. CASSIDY.

GEOLOGY.

Dating the Past, An Introduction to Geochronology; by FREDERICK E. ZEUNER. Pp. xviii, 444; 103 figs., 24 plates. London, 1946 (Methuen & Co., 30s).—To those who have read Doctor Zeuner's useful volume *The Pleistocene Period* (published in 1945 and reviewed in AMERICAN JOURNAL OF SCIENCE, vol. 244, 1946, pp. 373-376) the present companion volume will come as a welcome addition. Its author, Professor of Environmental Archaeology in the University of London, has developed it from courses of lectures into its present extensive and well-organized form.

Though it reflects its author's main interest in chronology, the earlier volume is a general treatise on the Pleistocene. The present volume, however, is unique in that it is concerned exclusively with chronology—or rather *geochronology,* which Doctor Zeuner defines as "the science of dating in terms of years those periods of the past to which the human historical calendar does not apply." The Introduction well states the scope and importance of the attempt to translate stratigraphic units into terms of absolute time—an attempt that has involved speculation and estimates, beginning more than a hundred years ago, as well as actual measurements dating from more recent time.

The monograph is very well arranged; it proceeds from geologically recent time back into the remote geologic past, systematically describing the various methods that have been used as bases of both estimates and measurements. These methods are discussed: (1)

Tree-ring analysis, extending over the last 3000 years, with principal reliance on the work of Douglass. (2) *Varved clay analysis,* extending over the last 15,000 years, with reference chiefly to the work of De Geer and Antevs. (3) *Deduction from calculated variations in the distribution of solar heat received by the Earth,* extending over the last million years. (4) *Measurements based on the rates of decomposition of radioactive elements in the rocks,* extending back into the early history of the Earth. It is the author's avowed aim to coördinate and correlate these various methods and to work toward a single continuous scale of geologic time which can be substituted for the relative, or stratigraphic, time scale in general use at present. He clearly indicates, however, that a great deal of study will have to be accomplished before this aim can be realized.

The present first attempt is a most useful guide to the whole subject of time counts. It represents an enormous amount of work in assembling a vast quantity of widely scattered information. The well-arranged references run to 650 titles in many languages; for this service alone geologists and archeologists will be deeply grateful to Doctor Zeuner. The entire discussion is clear, concise, and very readable; the reader can rarely have doubt as to what the author intends to say. The book is well illustrated with the tables and diagrams so necessary to a discussion of this kind, and with photographs of significant localities. A good index makes it easy for the reader to find his way through the great amount of useful detail.

To the present reviewer—who speaks only for himself—the only criticism that can be made in regard to this work is that it treats some aspects of geochronology without the rigorously critical approach that seems demanded. An uncritical attitude is apparent chiefly in the discussion of varved clay study and in the treatment of the problem of solar radiation.

With regard to varves, a good many geologists are skeptical of the objective reliability of correlations and would like to see the method thoroughly tested before placing great reliance on the chronology derived from it. Further, the gaps in the varve sequence established in eastern North America may be far greater than the values assumed for them by Doctor Zeuner's sources. We simply have as yet no reliable means of bridging the gaps.

Concerning solar radiation, this reviewer has already expressed the opinion that the adherents to the view that the so-called radiation curve had a profound influence on the Pleistocene climates, accept it somewhat too uncritically.[1] This opinion may be applied without unfairness to *Dating the Past.* The author compares the

[1] Geog. Rev., 36, 1946, p. 344-345.

radiation curve (p. 184) with the Pleistocene stratigraphic record in Europe (p. 110, 142) and obtains a coincidence which he thinks cannot be accidental. However, as both the stratigraphic record as interpreted, and the radiation curve, are open to question, the confidence felt by Doctor Zeuner in their agreement will not be shared universally. The trenchant criticism of the radiation curve made by G. C. Simpson[2] in 1940 is mentioned (p. 141), but it is not met, and this fact weakens the scientific position of the radiation curve. Furthermore the stratigraphic evidence from North America, which does not match the radiation curve, is ignored by Doctor Zeuner, who does not consider the Pleistocene stratigraphy of that continent at all.

Acceptance of varve chronologies and the radiation curve principle in *Dating the Past* will be accepted or rejected by geologists according to their own experience and judgment, for they possess a background against which they can evaluate many of the arguments advanced. But archeologists—notoriously thirsty for absolute dates—have a basis less firm than that possessed by geologists, for evaluating the reliability of the chronology presented. Some of them are likely to accept this chronology as fact, and to apply it to their own stratigraphy with confusing results.

Although we may admit that the point of view just expressed represents an extreme of skepticism, nevertheless the subject of chronology is too important to both geology and archeology to allow us to permit the growth of widespread misconceptions. The author states that the reader is free to reject the radiation curve; yet his entire discussion of the matter exhibits a strong bias in favor of that concept.

The same criticism cannot be made of the chapters (4, 6, 7, 8) that deal with archeologic stratigraphy. They present an encyclopedic summary of culture sites and cultural succession, particularly in Europe. The author is to be strongly commended for keeping scrupulously separate the geologic data, and the data from archeologic typology. He rightly points out (p. 146) that without such separation, stratigraphic confusion ensues, as indeed it does.

Both geologists and archeologists will find this book an excellent and useful reference work, and zoölogists will be interested in the final chapter, which is devoted to biologic evolution in relation to absolute time.

Errors are few. Fig. 82 needs correction, for it implies that Proterozoic, Precambrian and Algonkian are synonymous, and lists northern European correlatives of the Laurentian and Algoman for which there seems to be little if any basis.

RICHARD FOSTER FLINT.

[2] Linn. Soc. London, Pr., 152, 1940, p. 190-219.

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THE STRUCTURAL GEOLOGY OF THE DRAGOON MOUNTAINS, ARIZONA.

D. J. CEDERSTROM.

ABSTRACT. The Dragoon Mountains lie in Cochise County in southeastern Arizona. Cambrian quartzites and shales overlie pre-Cambrian granite and are succeeded by Devonian, Mississippian, and Permian (?) limestones and Cretaceous quartzites, shales, and limestones. These strata were intruded by granite and by rhyolite dikes during the Laramide Revolution. Low-lying areas are incompletely covered by younger alluvium.

During the Laramide Revolution the Paleozoic and Cretaceous sediments were greatly compressed. Cambrian strata rose along a low-angle overthrust fault and came to rest on upper Paleozoic and Cretaceous sediments. Overthrust blocks of resistant Cambrian quartzite cap several outstanding shaly peaks or knobs to-day.

Following the overthrust faulting, the sediments and their overthrust burden were folded. As the limit of compression by folding was reached, faulting along high-angle reverse fault planes took place. The Silver Cloud and Dragoon anticlines, the Sala anticlinorium, the Middlemarch syncline, and the Dragoon fault are the major structures that resulted from this phase of deformation.

Late normal faulting occurred on a small scale after the granite intrusion, which was concomitant with or followed the folding.

INTRODUCTION.

Location:—The Dragoon Mountains are in Cochise County southeastern Arizona and lie largely within township 23N and range 18E of the Gila and Salt River base and meridian. They extend from the mining towns of Gleeson and Courtland north-northwestward to Dragoon on the Southern Pacific Railroad, a distance of twenty-five miles. Historically famous Tombstone lies thirteen miles to the southwest and Bisbee, the important copper camp, is twenty-eight miles to the south. Pearce, an important silver producer in the years 1895 to 1929, is eight miles east of the Dragoons.

At both ends of the range granitic rock masses form outstanding peaks and rugged terrane. Cochise's Stronghold, a natural fortress once used by the Chiricahua tribesmen, lies

within the northern granitic mass. Southeast of the pinnacled Stronghold country lies a strip of sedimentary rocks nine miles long. This paper deals with the expanded northwestern portion of that strip. The area considered extends from a point one

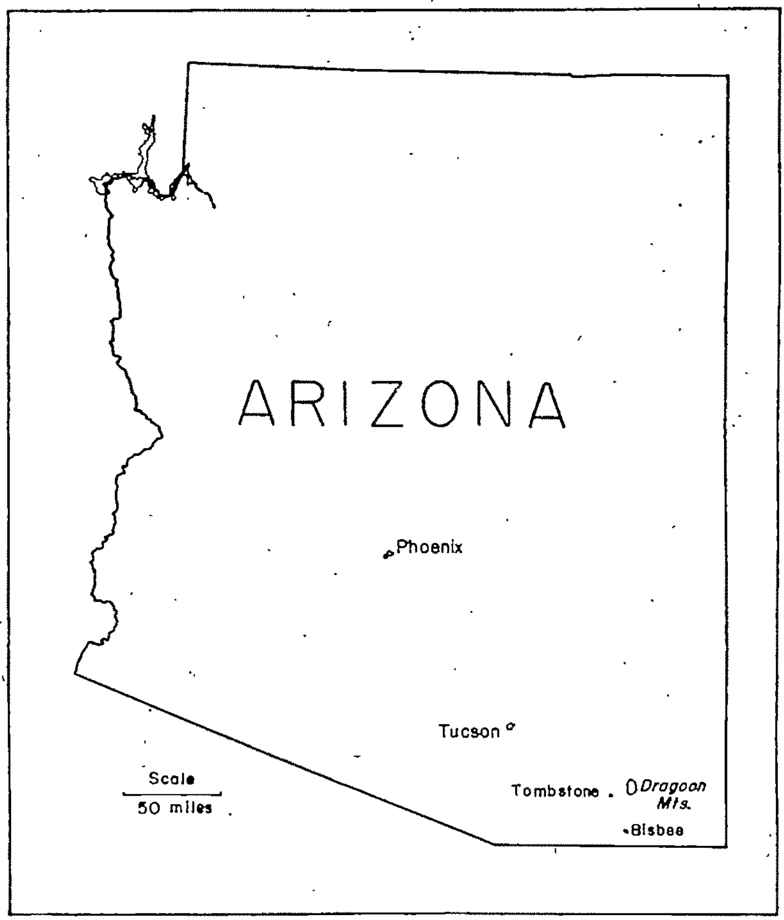

Fig. 1. Outline map of Arizona showing location of Dragoon Mountains.

mile southeast of Dragoon Camp to a point one mile northwest of Cochise Peak and is from two to three and one-half miles wide. The Middle Pass trail, which connects Tombstone with Pearce, divides the area into two equal halves.

Purpose of Investigation:—This paper presents a portion of a geological study made by the writer in partial fulfillment of the

requirements for the degree of Doctor of Philosophy in the Department of Geology of the University of Arizona. Field work was carried on during parts of the summers of 1932, 1933, 1934, and 1936.

Acknowledgements:—The writer is greatly indebted to members of the faculty of the Department of Geology of the University of Arizona for encouragement, help and advice given during the course of this work. Dr. B. S. Butler and Dr. M. N. Short visited the area several times and later checked some of the more important findings. Dr. Eldred D. Wilson and Mr. J. B. Tenney of the Arizona Bureau of Mines rendered valuable assistance in a like manner.

The writer is indebted to Mr. Adam Dodd and Mr. E. J. Kelley of Pearce and Mr. John Sala of Tombstone who provided living quarters for the writer and were otherwise helpful. Thanks are due other individuals who have also given assistance and constructive criticism.

PREVIOUS WORK IN ADJACENT AREAS.

In the Santa Rita Mountains,[1] 55 miles west of the Dragoons, "the main structural feature is a thrust fault dipping to the west." Sections show that the overthrust plane is strongly folded. In the Empire Mountains, east of the Santa Ritas, upper Paleozoic limestones have been thrust westward on Cretaceous sediments.

R. A. Wilson,[2] in a detailed study of a smaller portion of the Empire Mountains, mapped another thrust plane that dips gently to the west. He states that a period of high-angle faulting followed the overthrusting.

The structural history of the Bisbee area, 28 miles south of the Dragoon Mountains[3] may be outlined as follows:

1. Post Permian pre-Comanchean normal faulting (Dividend fault).
2. During the Laramide Revolution compressive stresses resulted in doming of the sediments around a resistant core of pre-Cambrian granite. South of the Dividend

[1] Schrader, F. C.; 1915. Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona: U. S. Geol. Survey Bull. 582, p. 93.

[2] Wilson, Roy A.: 1934, Thrust faulting in the Empire Mountains of southeastern Arizona: Jour. Geology, 88, p. 422.

[3] Ransome, F. L.: 1904. The geology and ore deposits of the Bisbee quadrangle, Arizona: U. S. Geol. Survey Prof. Paper 21, 106-107.

Fault the massive Paleozoic beds resisted doming and folding but developed large block faults (Copper Queen Block).
3. Low-angle overthrust faulting (Queen Hill Block).
4. Intense shattering by normal faults.

The compression is said to have acted from west to east.

In the Courtland-Gleeson area,[4] 12 miles to the southeast of the area considered in this paper and at the end of the Dragoon Range, thrust faulting of possibly late Tertiary age was preceded by a post-Cretaceous period of normal faulting. At Courtland the overthrust plane is approximately flat whereas at Gleeson it dips 20° southwest. Here, as in the Empire Mountains, thrusting is judged to be much later in time than at Bisbee, since "supposedly Tertiary" rhyolite has been involved.

B. S. Butler and E. D. Wilson[5] summarize the structural history of the Tombstone area in part as follows:

1. Possible mild Mesozoic volcanism.
2. Laramide folding along a northwest-southeast axis, accompanied by faulting.
3. Dike fissures develop, trending N16°E.
4. Strong faulting in approximately an east-west direction.
5. Fissuring along a southwest-northeast axis.
6. Normal faulting of post valley-fill age.
7. Intrusion of basaltic dikes.

Darton[6] has written briefly on the Dragoon Mountains. His cross-sections B and C correspond most closely with sections C–C′ and H–H′ in this paper. Darton recognized the structure here designated as the Sala anticline and the general southwest dip of the sediments making up both walls of Middlemarch Canyon. In his section C the easterly-dipping Paleozoics rock lying upon "Pinal schist," are shown to make up the high ridge in the southerly part of the area covered by this paper. Their relation to the folded Mesozoic sediments on the east is not clearly brought out. Porphyry dikes are shown, as is the gen-

[4] Wilson, Eldred D.: 1927, Geology and ore deposits of the Courtland-Gleeson region, Arizona: Ariz. Bureau of Mines Bull. 123, Geol. Series 5.

[5] Butler, B. S., Wilson, E. D., Rasor, C. A.: 1938, Geology and ore deposits of the Tombstone district: Univ. of Ariz., Bull. 143, IX, No. 1.

[6] Darton, N. H.: 1925, A résumé of Arizona geology: Ariz. Bur. Mines Bull. 119, 292–294.

eral relationship of the Stronghold granite to the sedimentary rocks. No suggestion of overthrust faulting is indicated and the map and sections are somewhat generalized.

GEOMORPHOLOGY.

Larger Physiographic Forms.

The portion of the Dragoon Mountains discussed in this paper consists of a belt of sedimentary rocks trending northwest-southeast which is dominated by a granite mass at its northerly end.

The southerly belt of sedimentary rocks, formed by the east limb of an anticline, makes a single high ridge which presents a steep face to the east where massive limestone overlies shaly beds. The ordinarily low, shaly terrane on the east is dominated by the resistant Black Diamond quartzitic thrust mass.

In that part of the area north of Santa Anna Gulch the belt of sediments splits into three prongs pointing toward the Cochise Stronghold granitic mass. All the sediments here are metamorphosed to some degree and are very resistant.

The longitudinal valleys are cut mainly in granitic rock and appear to have been controlled by extensive fissuring and faulting along the igneous-sedimentary boundaries. Unbroken granitic masses form outstanding blocks such as Cochise Peak, Sheepshead, and many unnamed lesser monoliths in the Stronghold to the north.

Major transverse canyons are almost lacking on the eastern side of the range due to the prevalence there of uniformly nonresistant shaly beds on the western side of the range. Santa Anna Gulch makes a deep canyon which heads into Middle Pass.

It seems probable that the Sorens Canyon originally drained southwestward across the wind gaps east of Silver Cloud Peak and above Middlemarch mine. A stream south of Silver Cloud Peak worked headward, pirated the main drainage line and thus reinforced, rapidly entrenched itself. The existence of such a major stream in this gulch is necessary to explain the deep dissection of this valley across the strike of massive limestone beds. However, the Santa Anna stream soon added the Sorens Canyon stream to its length, held it for a somewhat longer period of time than its predecessor, and finally gave it up to a tributary of the Middlemarch Canyon drainage system, as a result of which Middle Pass remains as a wind gap.

LESSER FEATURES.

The most conspicuous of the smaller topographic features are the porphyry dikes. Many stand out as ridges from a few feet to tens of feet in height and as much as a mile in length. A very prominent dike crosses Santa Anna Gulch; others are conspicuous on the floor and on either wall of Middlemarch Canyon. On the slopes and pediment below the Black Diamond camp the otherwise featureless topography of the shales is relieved by elongate, porphyry dike ridges.

DESCRIPTION AND DISTRIBUTION OF THE ROCKS.

The consolidated sedimentary rocks making up the Dragoon Mountains range in age from Cambrian through Mesozoic. Igneous rocks include a small exposure of pre-Cambrian granite, the widely distributed Stronghold granite which is intrusive into Mesozoic sediments, and porphyry dikes which intersect both the Stronghold granite and the Mesozoic sediments. The consolidated rocks are overlapped by unconsolidated late Tertiary or Pleistocene gravels.

PRE-CAMBRIAN.

The pre-Cambrian Apache group[7] of sedimentary rocks has been found as far south as the Little Dragoon Mountains,[8] 10 miles to the north, but appear to be absent in this area. A small mass of pre-Cambrian granite crops out in an arroyo in the extreme southerly part of the area and is unconformably overlain by Cambrian quartzite. It is a dark-greenish-black porphyritic rock carrying many small foreign schist fragments. Most of the phenocrysts make up more than half of the rock.

PALEOZOIC.

The Paleozoic rocks are those typical of the southern Arizona Basin as distinct from those deposited north of the Mazatzal

[7] Ransome, F. L.: 1914, Some Paleozoic sections in Arizona and their correlation, U. S. Geol. Survey Prof. Paper 98K, p. 131-141.

[8] Stoyanow, A. A.: 1936, Correlation of Arizona Paleozoic formations, Bull. Geol. Soc. Amer., 47, p. 474.

Cook, Frederic Stearns: 1938, "The geology of the Seven Dash area, Cochise County, Arizona," Master's Thesis, Univ. of Arizona.

Enlows, Harold Eugene: 1939, "Geology and ore deposits of the Little Dragoon Mountains," Doctor's Thesis, Univ. of Arizona.

Land[9] barrier which extended from southwestern to central Arizona in Paleozoic times. The sedimentary rocks are the Bolsa quartzite, the Cochise sandstones and shales, and Abrigo cherty limestones, all of the Cambrian age, the Devonian Martin limestone, the Mississippian Escabrosa limestone, and Permian (?) limestones.

Bolsa Quartzite:—The Bolsa quartzite, of Middle Cambrian age, lies unconformably upon pre-Cambrian granite in the extreme southerly part of the area. There it is about 325 feet thick, but elsewhere it is thinner.

Small masses are present southwest of Sala Peak, but the quartzite attains its greatest areal development as thrust masses capping Black Diamond Peak, the Sentinel, and Grant's Hill.

The quartzite is a vitreous fine-grained rock, more blocky than slabby, white when fresh but yellow to pink on weathered surfaces. On Black Diamond Peak the quartzite is underlain by a basal conglomerate and thin conglomeratic layers are present in the middle part of the section.

Abrigo Formation:—In the extreme southerly part of the area, 435 feet of gray, slabby, thin-bedded limestones separated by closely spaced bands of chert are assigned to the Abrigo formation of Upper Cambrian age. The fifty feet of poorly exposed shales beneath the typical Abrigo rocks may represent the Cochise formation.[10]

The limestone is also well developed in the Paleozoic section west of Sala Peak and overlies the Bolsa on the Grant's Hill and Sentinel thrust masses.

Martin Limestone:—The Martin limestone[11] of upper Devonian age is about 350 feet thick in the southwestern part of the area. Here it is a moderately massive-bedded limestone in which are intercalated four thin sandstone or quartzite beds. The limestones are black, gray, brown, pink and buff, the darker hues predominating. A reef of silicified corals, characteristic of the Martin in southern Arizona, is present near the top of the section. Southwest of Sala Peak the Martin includes five strata, apparently thoroughly silicified limestones, from 4 to 20 feet

[9] Stoyanow, A. A.: op. cit., p. 461.
[10] Stoyanow, A. A.: op. cit., p. 466.
[11] Ransome, F. L.: 1904, Geology and ore deposits of the Bisbee Quadrangle: U. S. Geol. Survey Prof. Paper 21, 33-35.

thick. These light-colored beds stand out in sharp contrast to the drab background.

Escabrosa limestone:—The Escabrosa limestone of Lower Mississippian age[12] is a cliff-forming, massive bedded white to gray granular limestone, in places made up largely of crinoid stems. It is about 300 feet thick in the southern part of the area; smaller exposures are present south of Sala Peak and on the pediment east of Middlemarch Canyon. It is possible that some of the recrystallized limestone mapped as Permian (?) limestone in the northerly part of the area is really Escabrosa.

Permian (?) *Limestone*:—The Permian (?) limestone[13] is thinner bedded than the underlying Escabrosa limestone and the texture is finer grained. Some beds have a pinkish hue. Chert is common and occurs in irregular bunches and nodules and in thin layers. Lying above the cliff-forming Escabrosa, these strata make up the crest of the range from Silver Cloud Peak southeastward.[14] Similar strata are also found on Sala Peak and south of there along Santa Anna Gulch.

The recrystallized strata making up part of both walls of Middlemarch Canyon and extending into the head of Stronghold Canyon are most probably Permian (?) limestones as are other smaller areas in the northwest which are mapped as Permian (?).

MESOZOIC.

The Mesozoic rocks underlie a relatively large portion of the area; to the south they occupy much of the area east of the crest of the range; to the north they make up the ridge on which Aerie Peak is located. Smaller areas are found southwest of Aerie Peak and south of China Peak.

Along the Dragoon fault, east of the Sentinel and at the lower end of Middlemarch Canyon, the base of the Mesozoic is marked by a limestone conglomerate containing cobbles up to six inches in diameter in a limy matrix. This conglomerate lies unconformably upon the Paleozoic limestone. Its thickness is variable, but east of the Sentinel it is up to 100 feet thick. It is absent in other parts of the area. The limestone

[12] Ransome, F. L.: op. cit., pp. 42-54.

[13] Stoyanow, A. A.: 1936, Correlation of Arizona Paleozoic formations, Bull. Geol. Soc. Amer., 47,—. 522.

[14] According to Dr. A. A. Stoyanow, poorly preserved fossils collected from these beds by the writer have a Permian aspect; hence the Naco formation (now restricted to Pennsylvanian beds alone) appears to be absent.

conglomerate is suggestive of the Glance conglomerate of Bisbee,[15] but no definite correlation is proposed other than that these rocks and the overlying shaly series are correlated with the Bisbee group (Lower Cretaceous) as a whole.

Above the limestone conglomerate, or directly upon the Permian (?) limestone where the conglomerate is absent, lies a series of sandstones and shales whose maximum thickness is unknown. The full thickness may be nearly 3000 feet, but, since the section may have been repeated by faulting, the total thickness may be only about 1000 feet.

The lower 100 feet of material above the limestone conglomerate is predominately quartzitic. Higher in the section the rock is shale with subordinate intercalated sandstones; individual shaly members may be as much as 100 feet thick, whereas the sandstone members are rarely more than 20 feet thick. Red and red-brown colors predominate.

The southwest wall of Sorens Canyon between Santa Anna Gulch and Aerie Peak is made up of a series of epidotized, garnetized, and highly silicified rocks in which wide streaks of black hornfelsic material is intercalated. These overlie about 200 feet of quartzitic and shaly material which in turn rests upon the Paleozoic limestones.

On weathered surfaces the strata have a brown nondescript appearance and are pitted where garnet and epidote have weathered out. B. S. Butler has stated[16] that these rocks are similar to the series of rocks lying above the typical lower shales and sandstones of Mesozoic age in the Tombstone area. The description of the "Novaculite" from that area[17] seems applicable in large part to these rocks.

The variously metamorphosed rocks making up the southwest wall of Sorens Canyon have a minimum thickness of 400 feet, but northwestward they increase to more than 1000 feet.

PRE-CRETACEOUS DEFORMATION.

The Mesozoic rocks everywhere rest upon Permian (?) strata. No suggestion of angular unconformity was noted. Hence the

[15] Ransome, F. L.: op. cit., p. 56.

[16] Oral communication, Aug. 17, 1934.

[17] Butler, B. S., Wilson, E. D., Rasor, C. A.: 1938, Geology and ore deposits of the Tombstone district: Univ. of Ariz., Bull. 143, IX, No. 1, 19-20.

post-Paleozoic pre-Cretaceous deformation of the Bisbee area has no counterpart in this portion of the Dragoon Mountains.

THE STRONGHOLD GRANITE.

Relation to the Sedimentary Rocks:—The coarse-grained granite making up the Cochise Stronghold mass extends southward as narrow bands into the area and the borders of the mass itself fall within the northern and western limits of the map.

With one minor exception the granite-sedimentary contacts, where well exposed, show that some movement has occurred along the contact. The granite is not frozen to the walls but is everywhere separated from the sedimentary rock along a sharp plane. Apophyses or stringers nowhere extend into the sedimentary rocks. Breccia is present in the sedimentary rock at the contacts at the head of Middlemarch Canyon. The Cobraloma adit passes through to the contact and along it for about thirty feet exposing a face of slickensided granite on the contact. Gouge is present in many other places and shear zones along the contact are general. These data seem to indicate that the granite has been faulted against the sedimentary rocks.

However, when the pattern made by the granite within the area of sedimentary rocks is considered it appears most likely that the granite is intrusive. The granite occurs within the sedimentary rock area in the following structural forms: a long dike (extending southeastward along Sorens Canyon), a shorter tapering dike (Middlemarch Canyon), a small wedge (south-southwest of China Peak), and a plug (on the east wall of Middlemarch Canyon). These forms are considered to indicate that the rock is intrusive.

When the metamorphism of the sedimentary rocks in the northerly area is compared with the lack of metamorphism in the southerly area, a compelling argument is advanced for the intrusive nature of the granite; near the head of Sorens Canyon the rocks are now largely hornfels, schistose rock has been developed southwest of China Peak, and the Paleozoic limestone rocks have been recrystallized, bleached, silicified and mineralized.

Description:—The Stronghold Granite in most places is white where fresh and light yellow where weathered; it has a medium to coarse-grained texture and may be described as porphyritic, although the porphyritic character is not everywhere readily

apparent in the hand specimen. The phenocrysts are stubby euhedral orthoclase feldspar grains.

The Stronghold granite is intrusive into Mesozoic rocks and is considered to have been implaced during the Laramide Revolution, following the folding of the range.

MINOR INTRUSIVES.

Aplite:—In several places a late aplitic granite is present as small dikes generally less than a foot wide. These intrude both the sedimentary rocks and the Stronghold granite.

Rhyolite sanidine porphyry:—Near Salas ranch house are two small dikes of pink rhyolite porphyry which are intrusive into Paleozoic rocks. The rock contains phenocrysts of euhedral quartz and sanidine feldspar.

Rhyolite albite porphyry:—The topographically impressive system of rhyolite porphyry dikes have already been mentioned. This porphyry is brown to lavender on fresh or weathered surfaces. It contains phenocrysts of quartz, albite feldspar, and subordinate pyrite.

The dikes are vertical or almost vertical in attitude and nearly all of them trend northwest-southeast. Since these dikes are intrusive into the Stronghold granite, they are regarded as a late differentiation product of the same parent magma.

Diabase Dikes:—Short narrow diabase dikes have been found in a number of places. These intersect both the sedimentary rocks and the Stronghold granite. The diabase is characteristically black or greenish-gray aspect where weathered.

STRUCTURAL DEFORMATION.

Except for the recent unconsolidated detritus skirting the range and partly filling the deep canyons, no sedimentary rocks in the central Dragoon Mountains remain in their original undisturbed position. Great stresses, acting from the southwest or northeast, have crumpled and broken the strata into many units. Other deformation of lesser magnitude has also been active.

A summary of the structural events is as follows:

1. Sedimentation in the Paleozoic and Mesozoic eras.
2. Low-angle overthrust faulting, probably acting from the southwest.
3. Folding of the sediments into broad open folds. Reverse

faulting took place where competent strata were unable to fully adjust themselves to the compressive forces by folding.

4. Intrusion of the Stronghold granite and associated dike rocks. Minor normal faulting followed volcanism.

THE FOLDS.

Folds dominate the structure of the portion of the Dragoon Mountains discussed in this paper. Later faulting has destroyed the unity of these folds and granite has obliterated parts of them.

In the southerly part of the area two parallel anticlines, axes of which fall on either side of the range, trend northwest and southeast. They are in contact along a reverse fault.

Silver Cloud anticline:—The Silver Cloud anticline, on the southwestern side of the range, makes up the two spurs extending west and southwestward from Silver Cloud Peak. On the southwest spur the Abrigo, Martin, Escabrosa, and part of the Permian (?) formations are well displayed (section F–F′, Fig. 3). Due to a gentle northwest pitch of the fold, however, the more northerly spur does not reveal the Abrigo limestone at the surface. The massive limestones dominate the structure and they crop out with a broad bold sweep. Thin-bedded Abrigo limestones exposed in the arroyo southwest of Silver Cloud Peak have responded differently to compression. Here a complex system of tight, contorted, and overturned drag folds strongly contrast with the broad arch of the overlying massive limestones. In the most southerly portion of the map area, the Paleozoic formations of the northeast limb are well exposed; the southwest limb, of which only a small portion crops out, has been faulted against the pre-Cambrian core of the fold and the upper part of the Devonian limestone lies upon it (section G–G′).

The northeastern limb of the Silver Cloud anticline is brought against the Mesozoic shales along the Dragoon fault. The fault is a warped plane dipping steeply southwest, and where the Paleozoic rocks make a reentrant into the Mesozoic rocks a synclinal structure is developed. Two such synclinal embayments are present; one at the southeast end of the range and one just east of Silver Cloud Peak (section H–H′ and F–F′, Fig. 3).

Section G–G′ is taken where the Dragoon fault trends westward and the synclinal development of the northeast limb of the

Silver Cloud anticline, is lacking; unlike section H–H′, therefore it does not show all the elements of the original structure. Section G–G′ shows the basal Mesozoic conglomerate lying upon the Paleozoic rocks in sedimentary contact and establishes the fact that the full (local) thickness of Paleozoic rock is present there.

To the northwest the Silver Cloud anticline is limited by a cross fault of small displacement.

Black Diamond anticline:—The axis of the Black Diamond anticline lies on the northeasterly slope of the range; the entire fold lies within the Mesozoic sediments (sections F–F′, G–G′, and H–H′, Fig. 3). The northeastern limb is well exposed on the slopes below Black Diamond Camp and the southwestern limb higher on the slopes beneath the cliff-forming Glance. This anticline, unlike the broad arch of the Silver Cloud anticline, appears to be a sharp crease separating two series of isoclinal sediments.

Northwestward the axis of the Black Diamond anticline is replaced by granite, but the northeast limb is seen on the prominent ridge just east of the Sentinel (section E–E′, Fig. 3). The limb is made up of Mesozoic massive limestone conglomerate and overlying shales, underlain by limestone bearing abundant brachiopods, considered to be Paleozoic in age. Southeast plunge of the anticline is thus indicated. It may be surmised that the basal Mesozoic conglomerate which crops out near the Sentinel lies only a short distance below the anticlinal axis south of Black Diamond Peak.

The Silver Cloud and Black Diamond folds are considered to have been part of the same structure. This structure was broken by a fault along which the Silver Cloud anticline rose a minimum of 500 feet (section G–G′), bringing Paleozoic rocks on the west side of the range to a level comparable to the Mesozoic rocks on the east.

The northern portion of the area considered in this paper differs markedly from the southern portion discussed above. Taken as a whole, the northern area may be said to consist of an anticlinorium on the southwestern side of the range, the northeastern limb of which develops into a syncline (section D–D′), the axis of which lies in Sorens Canyon. The northeastern limb of the syncline forms both walls of Middlemarch Canyon. Northward increasingly greater portions of the structure give way to the Cochise Stronghold granite mass.

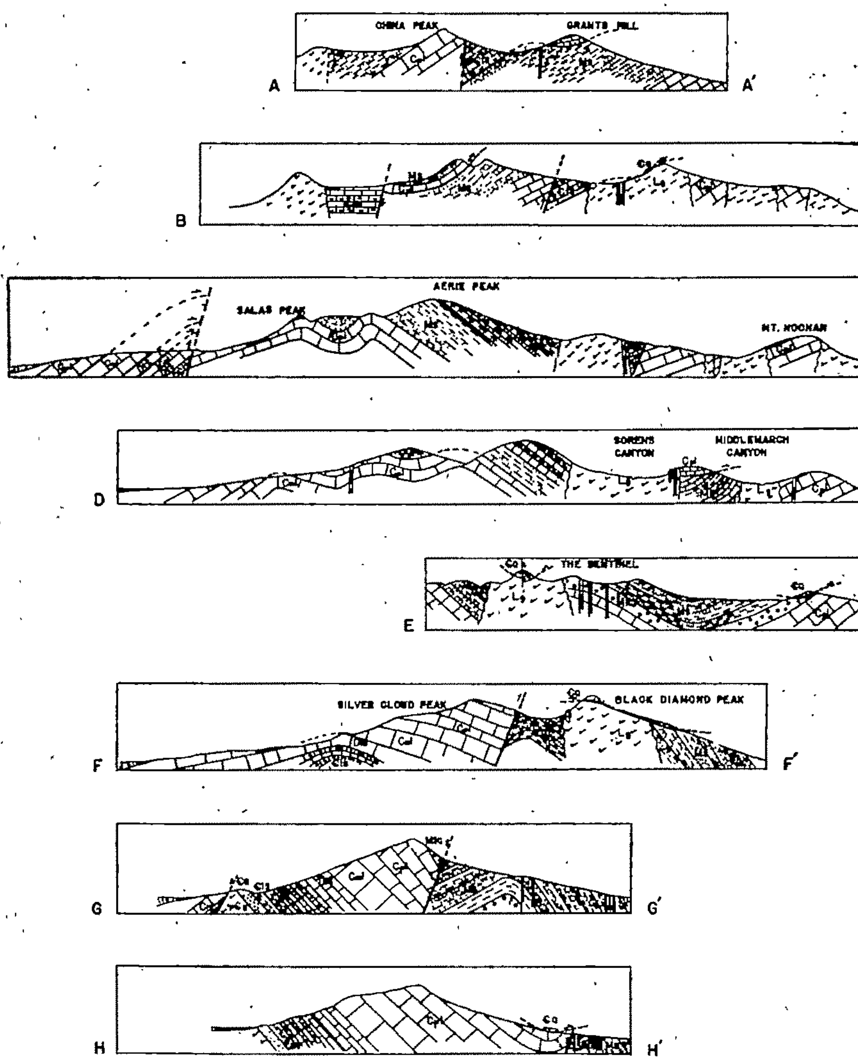

FIG. 2, GEOLOGIC CROSS SECTIONS
OF THE DRAGOON MOUNTAINS, ARIZ.

Middlemarch syncline: The northeast limb of the Black Diamond anticline has been traced northward to a point directly west of the Sentinel where the Mesozoic conglomerate forms a ridge. Northeast of the Sentinel, across the mouth of Middlemarch Canyon, the conglomerate again crops out. There it is underlain by Paleozoic limestones which have a southwest dip; a syncline, here called the Middlemarch syncline, is evident (section E–E′, Fig. 2).

The rocks making up both walls of Middlemarch Canyon dip to the southwest (sections D–D′ and C–C′, Fig. 2) and both are therefore considered to be part of the northeast limb of the Middlemarch syncline. The axis of the syncline trends west-northwest, but flexes westward at the mouth of Sorens Canyon and passes northwestward. A corresponding flexure along the strike has been observed in the massive Paleozoic limestones on the ridge southeast of Noonan Peak (Fig. 2).

The southwest dipping strata making both walls of Middlemarch Canyon may be traced northwestward to Stronghold Canyon with moderate continuity. Thus an unbroken series of folds (the Middlemarch syncline and Black Diamond anticline) appear to extend from the southeasternmost part of the area to Cochise Peak. This contrasts with the dissimilar folds on either side of Santa Anna Gulch on the western side of the range and it is believed therefore, that the transverse fault mapped in Santa Anna Gulch which separates them dies out northeastward except for the flexures mentioned.

Sala anticlinorium: In the area south of the Aerie it is seen that the Sala anticlinorium consists of three distinct anticlines with intervening synclines (section D–D′). The three anticlines occur within about the same distance across the strike as that required by the Silver Cloud anticline, but the Sala anticlinorium and the Silver Cloud anticline are not considered to be parts of one structure. It is thought that the strata north of Santa Anna Gulch, although possibly continuous with the strata to the southeast in the early stages of folding, acted as an independent unit and were shortened a relatively greater amount and are now separated from the Silver Cloud anticline by a cross fault of small displacement as noted above. The offset at the head of Santa Anna Gulch is cited as evidence for this interpretation.

The folds south of Aerie Peak strike about N45°W and plunge less than 5° to the southeast. The two higher anticlines

are traced to the spur connecting Salas Peak with the Aerie. The projection one-half mile northwest of this point is hypothetical in part because metamorphism of the strata has largely obliterated the bedding planes and salient characteristics. Directly west of Salas Peak the simple folded structure is destroyed. Bolsa quartzite of the Cambrian is brought up to a high level and a mashing of the structure by some force acting obliquely to the strike is suggested.

The lowest of the three anticlines shown in section D–D′ is traced west-northwestward where it breaks into a series of imbricate reverse faults. They are considered below.

The folds in the Gordons claims area are not continuous with those of the Sala anticlinorium but are separated from the latter structure by a cross fault. Here, within a basin-like depression (section B–B′), a slightly warped lower Paleozoic section has been brought against Mesozoic shales by a reverse fault. The Mesozoic shales themselves bear a thrust mass of folded Pennsylvanian limestones directly upon them. Presumably the Mesozoic strata beneath the thrust mass are folded as well. The strata may have been continuous with the rising Sala anticlinorium but greater relief was gained by faulting and a markedly different structure was created.

FAULTS ASSOCIATED WITH FOLDING.

In several places the strata were unable to obtain full relief by folding during periods of mountain building and further relief was gained by reverse faulting. In addition, important cross-faulting occurred at this time.

Dragoon fault: The Dragoon fault, the trace of which extends northward for a distance of almost three miles from the southern limit of the area, is a high-angle reverse fault. Where it crosses the deep gulch southwest of Black Diamond Peak the fault plane dips about 75° to the southwest. One-half mile north of Silver Cloud peak the Dragoon fault is lost in the granite; however, there seems to be no necessity to postulate its northward continuation into the area east and southeast of Aerie Peak.

At the head of Middlemarch Canyon Mesozoic sediments rest on Paleozoic rocks along a fault dipping steeply to the southwest. This is considered to be a reverse fault, related in time to the Dragoon fault, and possibly an offset continuation of the Dragoon fault.

On the westerly side of the range, a well-defined, high-angle reverse fault which dips 80° to the southwest (section C–C′) crosses the saddle on the spur extending south-southwest of Salas Peak. Immediately to the southeast Cambrian, Devonian, and Mississippian strata have locally been brought to the surface along lower-angle reverse faults which probably originated as bedding faults. All these faults tend to merge and pass into a fold a short distance to the southeast; hence they are genetically related to the early period of folding.

Miscellaneous strike faults: In the extreme southern part of the area Martin limestone of the pediment lies against pre-Cambrian granite along a fault plane which dips 45° to the southwest. Here normal faulting accompanied the rise of the massive granite and quartzite along the pitch of the Silver Cloud fold.

In the basin-like area south of China Peak a fault is postulated between the warped, low-angle reverse fault block and the lower Paleozoics immediately to the southwest. On the hill above Middlemarch mine a wedge-shaped block of Mississippian limestone rests upon Mesozoic limestones. This small overthrust is classed with the faulting movements developed concomitantly with the folding, because it has affected younger strata than those of the large overthrust sheet, remnants of which entirely surround this area.

Cross faults:—The cross fault mapped in Santa Anna Gulch separates the Silver Cloud anticline (which pitches to the northwest) from the Sala anticlinorium (which pitches to the southeast). An offset along this fault is seen at the head of Santa Anna Gulch. Since the Middlemarch syncline continues unbroken across the eastward projection of this fault, the fault is considered to pass into a cross fold at the mouth of Sorens Canyon.

A second cross fault that extends from a point south of Gordon's Claims northeastward across the backbone of the range and across the southwest wall of Middlemarch Canyon.

One half mile south of Gordon's Claims prominent Paleozoic limestones are abruptly terminated in a deep gulch. The northeastward continuation of the fault postulated here separates the infaulted Cambrian of the early overthrust sheet on the southwest wall of Sorens Canyon (section A–A′) from the

Mesozoics farther on down the canyon. The cross fault on the wall of Middlemarch Canyon just above the Cobraloma prospect may be a further continuation of this fault.

Cross faults of smaller magnitude mapped in the northwesterly portion of the area are lost upon entering the Mesozoic shales.

Direction of force: Good determinations of the inclination of axes of the folds have not been made. However, the inclination of the planes of high- and low-angle faults associated with the folding indicate conclusively that the force creating the folds and faults came from the southwest.

THE OVERTHRUST.

Preceding the post-Cretaceous folding, the initial compressive forces caused a flat-lying sheet of lower Paleozoic rocks to override Mesozoic and Upper Paleozoic strata. The thrust sheet was involved in the later folding and faulting, was partly assimilated or stoped by granitic intrusion and has suffered greatly from erosion. Portions of the thrust mass do remain, however, and crown the Black Diamond and less majestic peaks.

Grant's Hill:—On Grant's Hill, at the head of Sorens Canyon, the overthrust is composed mainly of thin-bedded Abrigo limestone, but on the northeast and southeast sides of the hill the underlying Bolsa quartzite crops out (section A–A′). These Cambrian strata rest on steeply dipping Mesozoic shales which pass entirely beneath the hill and appear again on the other side. This thrust mass, projected, forms the southwest wall of Sorens Canyon (section A–A′). The steep southwest dip indicates a later folding of the thrust plane.

On the prominent spur extending northward from Cochise Peak are two small "islands" of thin bedded Abrigo limestone (Fig. 2), each of which is entirely isolated and rests on granite. They are remnants of the larger thrust sheet which covered this area. The lower portion of these blocks has been stoped out or replaced by granite. It seems then that the Grant's Hill mass forms the crest of an arch over this part of the range.

A small remnant of Bolsa quartzite lies on the south slope of Cochise Peak. Half a mile down the canyon from Cochise Peak and west of the Sentinel are two other quartzite masses of similar character.

The Sentinel:—An outstanding hill known as the Sentinel is capped by a mass of Bolsa quartzite dipping to the southwest.

The northeast portion of the mass has been dropped slightly by late normal faults; 50 feet of typical Abrigo limestone lie above the quartzite in the down-dropped northeastern block.

A small quartzite mass on the southeast wall of Middlemarch Canyon (northeast of the Sentinel) rests upon Mesozoic limestone conglomerate. Immediately to the northwest of this mass another rests upon Paleozoic limestone and half a mile to the northwest a third very small isolated quartzite mass also rests upon Paleozoic limestone. These are all considered to be Bolsa quartzite and part of the folded overthrust sheet of which a portion forms the Sentinel.

Black Diamond area:—Black Diamond Peak is a large quartzite mass resting on granite and Mesozoic shales which dip northeastward. The northwest-southeast alignment of the quartzite cappings from Grant's Hill to the Black Diamond, the structural similarity of Black Diamond quartzite to the rocks capping the Sentinel and Grant's Hill, and the fact that the quartzites forming Black Diamond Peak extend to a lower elevation and rest with angular unconformity of Mesozoic shale and the appearance of the rocks themselves are considered as reasonable proof that these rocks are the Bolsa quartzite.

On the north and northeast slopes, lower than the peak by two to five hundred feet, large detached quartzite blocks immediately suggest slump masses derived from the peak or segments lowered by block faulting. Directly east from the peak on one less deeply cut spur the quartzite forming the peak descends 1000 feet and the mass as a whole is seen to be folded and corresponding roughly in structure to the Black Diamond anticline.

A mile and a half southeastward of Black Diamond Peak a massive quartzite block rests on upper Paleozoic limestones. This mass, lying within a syncline of upper Paleozoic rocks, is considered to be a thrust block of Bolsa quartzite similar in character and history to the Black Diamond, Sentinel, and Grant's Hill thrust masses.

In summary, then, five well-defined thrust masses of Cambrian strata are found in the area mapped. Two of the blocks rest entirely or in part upon Mesozoic shales, one rests on the basal Mesozoic limestone conglomerate, and one upon Upper Paleozoic limestone. The sole upon which the Sentinel mass rests has been replaced by later granite.

Age of Overthrusting:—The time of overthrusting cannot be proved conclusively, but the evidence that can be cited indicates

the overthrusting preceded the folding. The reasons for considering the overthrust early in time are briefly summarized as follows: first, there is a reasonable similarity between such folds as the Middlemarch syncline and the Black Diamond anticline and the warped overthrust masses; second, the thrust masses are almost conformable with the underlying sole rocks—lack of conformity in places is ascribed to the rumpling of shales by the overriding mass; third, several blocks are in protected positions (on the assumption that the thrust came from the southwest) and their later emplacement would necessitate an extremely warped thrust plane; fourth, the thrust plane intersects only uppermost Paleozoic and lower Mesozoic sediments; fifth, at the head of Sorens Canyon the thrust block has been involved in a reverse fault similar in character to and possibly a continuation of the Dragoon fault and hence almost certainly present before folding.

LATE NORMAL FAULTING.

In a few places high-angle normal faulting took place at a definitely late stage. On Grant's Hill, the Sentinel, and perhaps Black Diamond Peak, the quartzite thrust masses drop off in successive little steps in an eastward direction. These faults trend with the range and regional structure. They are regarded as resulting from settling movements that took place after compression had ceased. However, since small offsets are present from place to place in the granite-sedimentary contacts, they are more likely to be related to forces exerted following the intrusion of the Stronghold granite, the last major event recorded in the geologic history of the area studied.

RÉSUMÉ OF GEOLOGIC HISTORY.

The geologic history of the area may be summarized as follows: In pre-Cambrian times igneous intrusion of older, probably schistose, rock took place. By the end of pre-Cambrian time the region had been eroded to low relief. The Paleozoic sediments deposited are typical of those laid down in the southern and south central Arizona Paleozoic basin.[18]

In shallow seas of late Middle Cambrian time the Bolsa quartzite and Cochise shales were unconformably deposited upon the pre-Cambrian rocks. These quartzites were followed by shales

[18] Stoyanow, A. A.: 1942, Paleozoic Paleography of Arizona: Bull. Geol. Soc. Amer., 53, 1261-1269.

and thin-bedded limestones of the Abrigo formation of early Upper Cambrian age.

No trace of Ordovician or Silurian strata has been recognized. Martin limestones of Devonian age were laid down upon the Cambrian shaly limestones. Deepening of the Upper Devonian trough in Mississippian times led to the deposition of massive limestones upon the upper Devonian strata. Although Pennsylvanian and Permian times ushered in a new transgression of the sea, the Permian (?) limestones of the Dragoon Mountains rest upon the Escabrosa limestones without conspicuous break.

A period of erosion followed and in Mesozoic times the encroaching seas trapped coarse local material brought out of the higher land areas to form a basal conglomerate. Shallow seas persisted through much of the remainder of Mesozoic age and a great thickness of shaly sediments was deposited. The depositional basin was for the most part unstable, for quartzites, arkoses, shales, and limestones were deposited alternately and no single rock type appears to attain any great unbroken thickness. Tuffs, characteristic of the Mesozoic in other parts of southern Arizona, were not recognized.

Toward the end of Mesozoic time Paleozoic sediments were thrust northeastward (?) over the area and in places Cambrian strata came to rest upon Mesozoic shaly rocks. This movement was followed by crumpling of the sediments (and their overthrust burden) into moderately close folds. Massive and brittle strata broke when stressed too greatly and sought upward relief along both high and low angle faults.

Following the period of folding, a great mass of molten rock forced its way upward, stoping out large segments of rock in its path, pushing aside others and metamorphosing the adjacent sediments. Late, high-angle faults of small throw record a gentle settling at the termination of the compressive and igneous activity.

Further folding, faulting or igneous activity is not recorded in this portion of the Dragoons and orogenic forces appear to have been spent. The intense compression had raised these rocks to higher elevations. Erosion followed and in part stripped the pile to its core and buried the lower lying bases in a heavy mantle of alluvium. At a late date a slight uplift gave new vigor to the streams.

CHARLOTTESVILLE, VIRGINIA.

CRYOPEDOLOGY—THE STUDY OF FROZEN GROUND AND INTENSIVE FROST-ACTION WITH SUGGESTIONS ON NOMENCLATURE.

KIRK BRYAN

ABSTRACT. Cryopedology is suggested as a suitable name for the sub-science concerned with the study, both theoretical and practical, of intensive frost-action and permanently frozen ground. Sixteen other terms are also introduced and defined. Of these the important ones are pergelisol, permanently frozen ground, and mollisol, the overlying seasonally thawed ground in which intensive frost-action occurs. In areas where this action has ceased, the surface layer has been frost-disturbed or subject to congeliturbation. It is a congeliturbate—a term which includes all varieties of warp, trail, head, Coombe rock, solifluction deposit, Erdfliesse, etc. It is believed that these and the other suggested terms will facilitate discussion of the problems of the Arctic and of the ancient frost-action of periglacial areas.

INTRODUCTION.

STUDY of the action of frost, particularly in the Arctic and in areas having a periglacial[1] climate during the Ice Age goes on apace. However, discussion of the problems involved is handicapped and confused by the awkwardness and inadequacy of available terms. The present paper is concerned with the propriety of introducing some order into the terminology by the adoption of new terms and the modification of certain older ones. All future needs cannot be anticipated but the proposals here made should give a measure of relief.

ACKNOWLEDGMENTS.

I have discussed the questions of nomenclature here considered with many of my advanced students and with a few members of the U. S. Geological Survey. Dr. Herbert E. Wright, Jr., has been helpful. To Prof. Joshua Whatmough and Prof. Serge Elisséef, I am particularly grateful for advice on linguistic difficulties. Figures 1 to 8 are reproduced with permission of the authors and of the editor and publishers of the Geological Magazine.

[1] This term was introduced by Lozinski (1909) for (1) the area adjacent to the border of Pleistocene ice sheets; (2) the climate characteristic of this area; (3) and, by extension, the phenomena induced by this climate even if located outside of the main periglacial zone. The term is now well-established: Cailleux (1942), Zeuner (1945), Bryan (1928), Smith (1936), Denny (1936), Sharp (1942-A).

THE GENERAL PROCESSES.

In our textbooks discussion of weathering and erosion is largely confined to types of activity current in temperate climates. The relatively modest rôle of frost-action in temperate climates can be described with ordinary English words. "Frost" has, according to Webster, several meanings: (1) the act of freezing, applied chiefly to water; (2) the state of the air which occasions freezing; (3) frozen dew or hoarfrost; (4) metaphorically, coldness of temperament, etc. The first two senses are those commonly in use in geological discussions. The word is also a verb, "to frost," in which the meaning is more confused: (1) to frost or freeze vegetation; (2) to cover with hoarfrost and hence (3) to produce a "frosted" or matte surface on cake, metals, or other substances. In order to describe the action induced by freezing and thawing, geological writers have been forced to compound the terms "frost-action" and "frost-work." Webster does not define "frost-action" but the meaning of "frost-work" is given as the pattern of ice crystals on a window pane or other surface.

Thus the general use by geologists of "frost-action," "frost-work," "frost-splitting," "frost-split," "frost-riving," "frost-riven," "frost-heave" and "frost-heaved" is not completely supported by dictionary definitions. However, these terms are all perfectly derived verbal nouns and adjectives of self-evident meaning. There is, however, no way of deriving from these verbal expressions corresponding nouns for the products of the varieties of action that they imply. All that can be done is to use expressions such as "materials produced by frost-action," or "frost-split fragments" or "frost-heaved ground." Experience shows that such roundabout expressions are awkward and inadequate. Several terms have been introduced for particular frost-born products but no satisfactory general terms of wide connotation have yet been brought forward.

THE NEW SUB-SCIENCE—CRYOPEDOLOGY.

The present wave of interest in the Arctic stemming from the recent war, involves studies in both pure and applied science. This new drive will advance knowledge in a field which heretofore has been investigated for its own sake or for application to the problems of the Pleistocene. The construction of roads,

airfields and other facilities gives rise to problems new to American engineers and construction men. The extensive experience and studies by the Russians in Siberia have been summarized in the excellent manual by Muller (1945). New studies have recently been undertaken in Alaska by the U. S. Geological Survey and by the U. S. Engineers. This economic interest reinforces and adds a drive which means progress in the study of intensive frost-action and permanently frozen ground.

It appears that a new sub-science is being created and that it deserves a name. "Cryopedology" is proposed (see also Bryan, 1946) as a suitable name, being derived from krúos, κρύος, icy cold, pedon, πέζον, ground or soil and logos, λόγος knowledge. The Greek root "cryo" is familiar in the words cryolite and cryogenic and "pedon" in Pedology or Soil Science.

As thaw as well as freeze is an important factor in all the processes studied, it is unfortunate that the idea of thaw cannot be included without unduly lengthening the term. However, freeze and thaw are ideas so closely joined in our thought that one suggests the other. The term Pedology also is not as extensively used as one would expect because of confusion with Paedology, the medical science of children's diseases and care. Moreover, many soil scientists limit their work to the upper layers produced by soil process (weathering) whereas frost involves very considerable depths below the surface. However, Paleopedology is obviously concerned with weathering to any depth (Bryan and Albritton, 1943) and is thus a model for Cryopedology.

In the remainder of this paper the various processes and phenomena of Cryopedology are reviewed and a set of terms is proposed. The terms should be general in import and allow the retention of local and special terms. So far as new varieties are discoverable, new names may hereafter prove necessary. Local words with local connotations are so useful, particularly in reports of an economic import, that many of these terms should be retained as synonyms. The new terms are compounded so far as possible from familiar roots already established in English usage. They will, therefore, be readily converted into other European languages.

NEED FOR GENERAL TERMS.

Frost-action as a term involves a variety of processes and implied results. There are the phenomena of freezing. As

shown by Taber (1929 and 1930) the onset of low temperatures freezes the water in the pores of the ground but there is little resulting expansion. In a body of ground provided with capillary pores and connected to unfrozen water-bearing ground, ice continues to crystallize in layers and masses. Expansion of the frozen layer ensues and results in thrusts in all directions. As the direction of easiest relief of strain is upward, expansion of the ground in that direction is notable and is usually called frost-heave. However, the upward expansion is frequently highly concentrated at spots having the best capillary connections to the best water-supply. There is no common expression for the lateral thrust resulting from expansion although horizontal as contrasted with vertical frost-thrust would sufficiently carry the meaning. As shown by the studies of Taber (1929-1930) and of Beskow (1930) the physics of the process seem at present to require no new terms.

However, the thawing of frozen ground induces new movements. The frozen ground usually contains ice to a volume much greater than the volume of pore space. On melting the grains are separated from each other by films of water and the mass lacks coherence. There results differential and mass flow. Our present knowledge is insufficient to describe all the intricacies of this flow. The objective of many students is to analyze the movements completely. It is certain, however, that if the melt-water can escape, much fine-grained material is carried off. Further the body of melted ground is rearranged by differential movement and, if a gradient exists, there is also a mass flow down slope.

These movements may be arrested by a new freezing cycle and obviously the number of alternations from freezing to melting and their duration and intensity affect the movements. Further, every cold period is accompanied by evaporation of water and ice. The surface of the ground becomes loose and pulverulent. This dry layer also modifies movements on later melting.

The mass movement down slope was named by Andersson (1906) "solifluction" (from *solum*, soil and *fluere*, to flow). His term, not being strictly limited to flow under conditions of freeze and thaw, has been extended to cover soil flow under other conditions. Salomon-Calvin (1929), who restricts solifluction to motion over a base of permanently frozen ground, points out that those who use solifluction as synonymous with

"soil flow" need another expression for the process described by Andersson. This new term is here suggested.

Furthermore the movements of material under severe freezing and thawing are not confined to simple mass flow but are more complex. Fine-grained materials are winnowed out so that the surface layer is coarser than the base. Also the coarse and fine components of the surface layer move differentially so as to produce the much studied and highly varied "soil structures."

The down-slope movement of the fine-grained components is presumed to be largely a flow as mud and is called by English writers "sludging." Zeuner (1945) and Muller (1945) propose to call the product of "sludging" by the provincial English word "slud." Whether it is possible to make a distinction between materials which have flowed as labile muds and those washed off and carried off by melt water as held by Salomon and others is uncertain. The present use of "solifluction" and "sludging" implies that a distinction between two types of mass movement can be made.

What can be proved easily is that the surface layer, 1 to 3 feet thick and in places as much as 10 feet thick, has been disturbed and that some of its components have been translated down slope. The nomenclature here proposed emphasizes the disturbance rather than the fact or the method of down-slope movement.

In summation, the easily ascertained effects of intensive frost-action can be assigned to two groups of related processes: (1) the break-up of rock by freezing of water, a familiar process; (2) the differential and down-slope movement of the surface layer. The latter process, although it has been the subject of many studies over the past 30 years and in spite of the pursuit of these studies at an accelerated rate, is still not well understood. Most of the difficulties in nomenclature are in this field of effort. The literature is large. Steche (1934) has listed about 250 papers. The most penetrating review is by Lozinski (1934) and the American literature is increasing rapidly (Sharp 1942-B).

TERMS FOR FROST-SPLITTING.

The break-up of rock by freezing normally requires repeated freezing with intervals of thawing and results in the production of rock spalls and also in the comminution of rock into small grains. These phenomena are referred to as "frost-splitting"

or "frost-riving" and the fragments are said to be "frost-split" or "frost-riven." These are good English expressions and unobjectionable. They are paralleled by the German, *Frostsprengung* and *Spaltenfrost*. The slim crystals of ice which form at right angles to the ground surface are called needle ice, and in German, *Pipkrake*. However, no word is available for the product of frost-splitting either as individual pieces or as a mass. If comminution of rock is as important a process as contended by Bertil Högbom (1914) and by Taber (1943), then a word is necessary.

In compounding a new term, the obvious root is derived from Latin *gelo, gelare,* to freeze, and *gelu,* frost. There are many derivations in English, most of which refer to the formation of a jelly from a liquid, as gelatine, gelatinize, etc. However, "gelation" means to cool from a molten state and "regelation" is familiar as the process of refreezing of ice under pressure. The Latin, *congelare,* to freeze, is familiar in the word congeal, derived through the French, and the prefix *con* blurs the sound of *gel* (*i*) so that the compound becomes distinctive.

Thus for frost-splitting the word *congelifraction* is proposed from *congelare* to freeze and *fractare,* to break. There is then available the noun "congelifract" for the individual fragment produced. If the congelifracts are large, the body or heap of fragments or "spalls" is a rubble of congelifraction. But there are many kinds of rubble and precision is necessary if one is to distinguish between heaps of rubble produced by simple gravitational accumulation in a warm desert, and the rubbles of talus in a cool mountain area where most of the rock spalls are "congelifracts." Further, the comminution of rock into mineral grains by frost-action produces a distinct type of sand and finer fragments. Both large and small congelifracts would form bodies of material to be designated by the term "congelifractate."

TERMS FOR MOVEMENT UNDER FROST-ACTION.

As previously pointed out, the term solifluction is no longer strictly confined to flow under freeze and thaw (Sharpe 1938). A. Heim (1908) for instance has introduced "subsolifluction" for the flow and sliding of soft materials under sublacustrine and submarine conditions.

However, some authors such as the Abbé Breuil (1934) not only use solifluction for the process but also for the product.

Such usage may be justified in French grammar, but is not to be excused in English. Nor can the spelling "solifluxion" common in the writings of English authors be strongly defended. Many English authors use the expressions "solifluction deposit," "solifluction layer" (Zeuner, 1945). Others are slightly confused in their usage. Thus Paterson (1941 p. 5) says in a single paragraph, "Solifluxion 5 indicated a recrudescence of precipitation . . .;" "Subsequent to solifluxion 6 . . .;" "These gravels are capped by a weakly developed solifluxion 7. . . ."

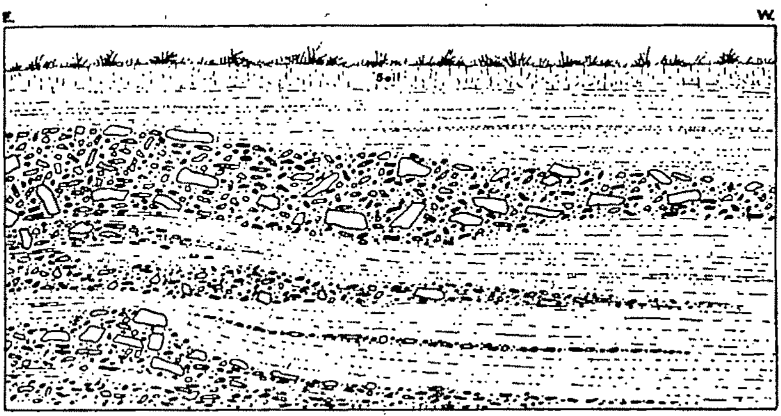

Fig. 1. Section of the Newlay Gravel Pit in Airdale, England, from Dines *et al* 1940. Drawing is without scale but height is about 10 feet. Shows interfingering of congeliturbate with water-laid sand and gravel of outwash terrace.

Here the process, the time involved and the deposit from which the two are inferred are inextricably entangled. Paterson (1941 p. 376) also uses "soliflual" as an adjective and as a noun, and the undefined term "suffosion bursts."

The existence of masses of unsorted material overlying bedrock and the older glacial tills has long been recognized in England. A brief history of thought has recently been published by members of the British Geological Survey (Dines *et al.* 1940). The literature begins in 1788 and from the beginning these deposits of rubble, clay and sand were recognized as formed: (1) by processes no longer in action; (2) as now subject to modern rain wash and weathering; and (3) in places dissected by streams or cut into bluffs by modern wave action.

The term "head" was introduced in 1839 by de la Beche but "Diluvium," "subaerial beds," "masses of detritus," "Angular

Flint Drift," "Angular Drift," 'Coombe Rock," "erratic warp," "warp," "trail," "clay with flints," "Rubble Drift," "Coombe Deposit," "Taele gravels," and "solifluction deposits" are terms used by various authors.

The discussion and illustration of Dines *et al.* are illuminating. In Fig. 1 here reproduced, they show frost-moved rubble interfingered with "late glacial" gravel, sand and silt in Newlay Gravel Pit. "The stony layers are packed with angular fragments of ganister [quartzite] and sandstone up to a foot in length and are obviously derived from a Coal Measures sandstone which crops out on the hillside 300 yards to the south, the slope being about 5°. Some of the ganister fragments show polishing which may be attributed to wind-driven sand."

The relation of frost-formed deposits to the limit of glaciation and to the outwash of the later stage of the New Drift [presumably equivalent to Middle Wisconsin] is shown in Fig. 2.

The frost-moved materials consist largely of rearranged boulder clay. The mappable portions are largely confined to side valleys and two of the patches pass laterally into the outwash gravels extending downstream from the terminal moraines. No frost-moved deposits occur within the glacial limit. Thus it is inferred on these lines of evidence that the mapped bodies were formed in the periglacial climate of the York-Escrick stage.

In the Axe Valley the lithologic character of the frost-moved materials varies with that of the bedrock in such a way as to prove down-slope translation. As shown in Fig. 3, the "head" at the top of the slope where it rests on chalk consists of "pebbly sand and clay" but at the outcrop of the underlying chert beds it changes into "angular chert drift." The content of chert dominates and this term is also applicable down slope in the area of the "upper greensand and Gault" formations which are free of chert, although materials from these rocks are incorporated.

These examples and the studies of many authors in England and Europe prove that deposits attributable to a more intensive frost-action at one or more intervals of the past are common phenomena.

Dines *et al.* (1940) reject the term "warp" which appears to have been introduced in 1847 and 1851 by Trimmer who showed that the surface materials of the hills of Norfolk and Kent were in part derived from the underlying rocks and in part

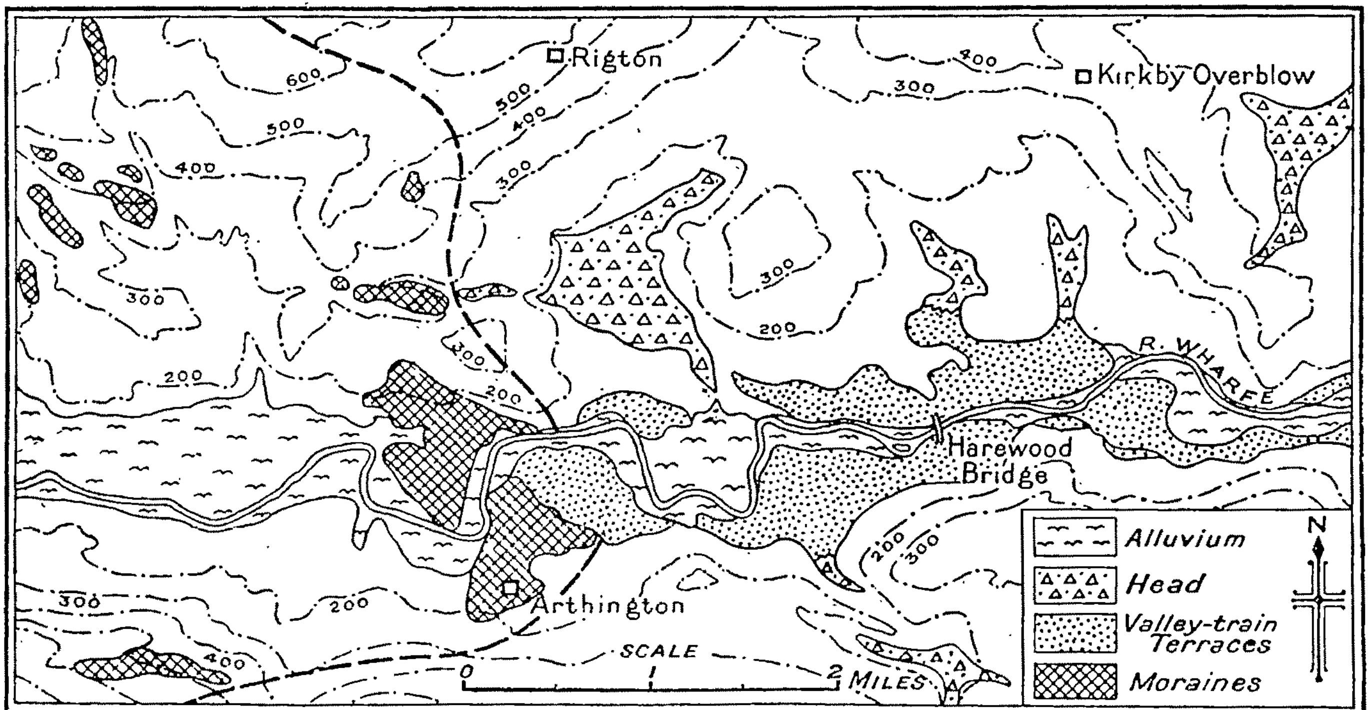

Fig. 2. Sketch map showing relations of the congelliturbate (head) to the valley train terraces of the New Drift in lower Warfedale, England. Broken line is approximate eastward limit of the final York-Escrick stage of the Newer Drift [Middle Wisconsin]. Blank areas are drift-covered Millstone grit. From Dines *et al.* 1940.

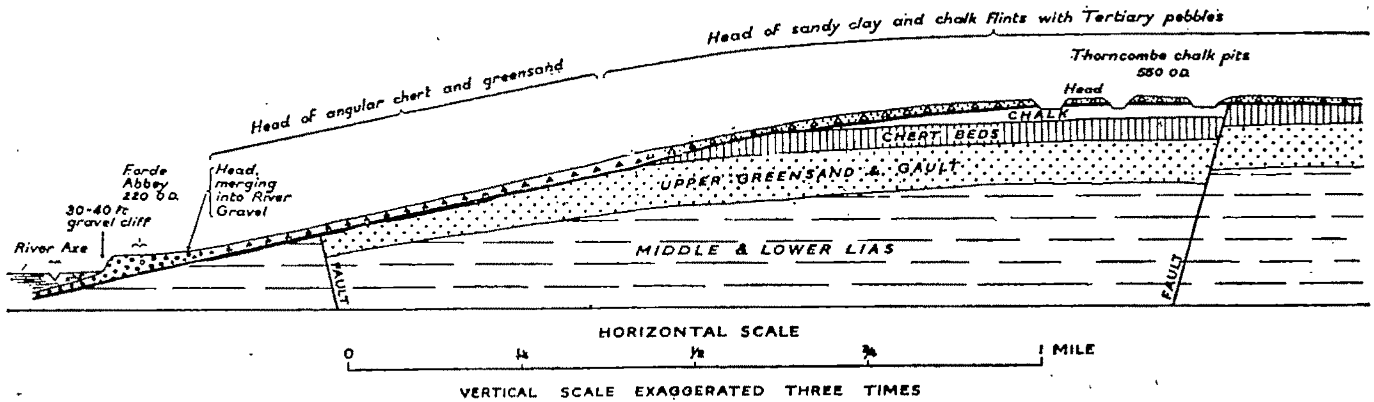

Fig. 8. Distribution of congeliturbate on slope of Axe Valley showing change in lithology with character of underlying rock and transition into outwash terraces. From Dines *et al.* 1940.

transported from up-slope. Fisher (1866) in a well-known paper described the "warp" as a blanket conforming to the slope and the "trail," a term introduced by Fisher, as a deposit in troughs or furrows more or less parallel to the existing minor drainage of the slopes. Dines *et al.* (1941) assert that Fisher considered "warp" or "warp of the drift" the soil derived from "trail." On rereading Fisher's paper it is obvious that he considered the "warp" as earlier than the present soil (p. 554). He considers that the "trail" is not only coarser than the "warp" and obviously derived from up-slope, but it is also older. It has contributed to the formation of the "warp." Fisher refers repeatedly (pp. 562-564) to the "warp" as older than the alluvium of present stream channels. He obviously believed that both materials were due to frost-action. His clearest statement is:

"We have, subsequently, though perhaps not in immediate sequence, a period of extensive denudation, indicated by the furrows filled with materials from the higher grounds, which have travelled in a plastic state, and which I have called "trail." This denudation brought the surface almost exactly to its present form. The period of the formation of the warp succeeded, in which the winter frosts seem to have been more severe than at the present time." (p. 564)

Trimmer (1847 and later) believed that the warp was formed by icy marine waters during the submergence of all of England at the close of the Ice Age. Hence, his use of the word conforms to, or perhaps gives rise to, one of the definitions in Webster: "a slimy substance deposited on land by tides, etc., from which a rich alluvial soil is derived."

Warp has been used in the sense of head by Sanford (1932) and doubtless others in England, but seems to have lost favor. It was introduced into the United States by Bryan (1928) and was subsequently used by Denny (1938) in his brilliant proof of the periglacial formation of frost-developed slopes and rubble masses in the Highlands of the Hudson.

The difficulty with these English terms is their provincial character and lack of distinctiveness when out of context. Each of them, head, warp, trail, etc., is an ordinary word with other and more familiar meanings. "Coombe Rock" is a mixture of fragments of chalk, flints, and other detritus. It and "Clay with flints" are both derived from the Chalk formations of England. They are distinctive but are local lithologic variants of

a general phenomenon and confined to England and France. Zeuner (1945) uses "frost soil" as a general term but obviously this compound strains the meaning of both its components. *Frost-boden* (frost soil) has also been used as the equivalent of permanently frozen ground. The German "Erdfliesse," "Brödelerde," etc., are awkward or imply too much. Further, neither the German nor the English terms are readily convertible into other languages.

It is obvious that a word is needed for the process and for the result. A recent coinage by Edelman, Florshutz and Jeswiet (1936) is "cryoturbation" which has been adopted by Cailleux (1942). The word is derived from the Greek, κρύος = icy cold or frost and τυρβάζω = to trouble, confuse or stir up. The root "cryo" is familiar but there are no derivatives of the verb although its equivalent, the cognate Latin *turbare*, is represented in turbine and other words.

An equivalent word can be compounded from the Latin *congelare*, to freeze with *turbare*, to stir up, to produce "congeliturbation." The product of the process of congeliturbation is a congeliturbate. That all varieties of ground moved by frost-action are moved differentially seems established. Thus, all are stirred up or disturbed. Therefore, congeliturbation and congeliturbate should include all varieties of process and all resulting materials.

The surface features of congeliturbation are most easily observed. A large literature has arisen and a very large number of names have been given to these features, mostly in German. Various suggestions have been made for corresponding English terms. Sharp's (1942-B) list of English equivalents is probably the best. He proposes that "soil structures" be used as a general designation to include as varieties: stone nets, stone rings, stone garlands, stone stripes, earth stripes, earth hummocks, and turf-banked terraces. These seven terms include some sixty-three terms in several languages. In cross-sections of congeliturbates, these structures are not usually identifiable. Dücker (1934) has, however, identified stone nets or stone rings in congeliturbates of Late Pleistocene age. Keilhack (1938), Sharp (1942-A) and others have described interdigitation of beds of sands and clay in dumb-bell-like projections. These phenomena Sharp (1942-A) refers to as "involutions," a satis-

factory neutral term for the structures (see also Denny 1934). German writers usually call the phenomena "Brödel-strucktur" which implies that they are due to the formation of soil structures according to the Low-Gripp theory. As, however, this theory (Gripp and Simon 1933-34) is still to be proved and is the subject of much doubt (Mortensen 1932; Sharp 1942A and B; and others), all terms involving "Brödel" should be avoided in description and neutral terms such as involution should be favored. A mass of involuted materials is, however, only a variety of congeliturbate.

The down-slope movement of the congeliturbate produces a drag on materials below, resulting in "drag folds" involving the underlying material and the congeliturbate. Such plications are referred to by some English authors as the "underplight" (Dines *et al.* 1940). However, the neutral and descriptive term plication seems adequate and is also applicable to those instances in which the "drag" phenomena involve only the congeliturbate.

The movement of fine-grained materials, mostly the finer products of congelifraction, to the surface is a significant part of congeliturbation. It is essential to the theories of formation of soil structures set forth by Eakin (1916), Högbom (1913), Gripp and Simon (1933-34) and others. This fine material is washed down slope in the yearly period of melting in streams or sheets of water or it may flow as mud. Taber (1943), Poser (1931) and others make much of this process. Insofar as the material flows as mud the process is included in solifluction. The English terms, "sludging" for the process and "slud" for the material, are neither euphonious nor necessary as such material can be referred to as a congeliturbate transported by solifluction or by sheet-wash as the facts indicate.

TERMS ASSOCIATED WITH PERMANENTLY FROZEN GROUND.

The process of congeliturbation is not confined to areas of permanently frozen ground. Salomon (1929) and others have shown that no permanently frozen ground exists in mountain areas where the process is now active in a minor way. However, in the areas of greatest intensity of frost-action of the Arctic, permanently frozen ground is involved. The terms perennially frozen ground and perpetually frozen ground are also in use. These trinomial phrases are all awkward and the equivalent

German and Russian is equally difficult.[2] There has been a movement, mostly among Scandinavian and German authors to introduce *tjaele* or *tjoele,* a Swedish-Norwegian word with equivalent meaning (Beskow 1930; Huxley and Odell 1924). It is, however, a word difficult for non-Scandinavians to pronounce. Muller (1945) in his useful review and analysis of Russian studies of the Arctic has sought the obvious convenience of a single word for permanently frozen ground by coining "permafrost."

"Permafrost" has the merit of being euphonious, but it is an etymological monstrosity, made by contracting "permanent" (through French from Latin, *permanere*) and combining it with the English word "frost," none of whose meanings refer to the ground. It sounds like a trade name for a refrigerator and "permaform" and "permalift" actually exist as the trade names of types of brassieres. There is also a glue named "permacel." These slight crimes might be forgiven, but it is impossible to make a verb or a verbal noun from "permafrost" as "permafrosting" and "permafrosted" imply that a permanent surface or coating has been applied. Hence the act of producing permanently frozen ground cannot be expressed. Further, the term cannot be easily converted into other European languages.

These various objections can be met by a new term which, being compounded from Latin roots already established in English usage, would convey a meaning on its face. Such a word is "pergelisol" from *per*= throughout or continuing+*geli* =*gelare,* to freeze+sol, from *solum,* the soil or ground. In this term the use of the prefix "per" blurs the resemblance to gelatine and other derivatives of *gelare* with the connotation of jelly.

The several modifications and attributes of the permanently frozen ground pointed out by Muller can then be easily made: "subgelisol," "supragelisol." and "dry pergelisol."

One of the great problems of the Arctic is the time and manner of formation of the pergelisol. To what extent is the area now occupied strictly in accordance with modern climate? Johnstone (1930) has recorded frozen ground at depths of 30 feet below the surface and thus obviously below the depth of present day freeze and thaw. It must be fossil. The question is thus raised as to what extent part of the pergelisol may be

[2] German: Ständigen-, dauernden-, und ehigen-Frostböden oder Bödengefrornis; Russian: vechnaya merzlota.

residual from the colder climate of the Pleistocene? The great areas of congeliturbates in periglacial areas imply that pergelisol was also present. Thus future discussion will involve again and again the process of formation of pergelisol. It is suggested that the term "pergelation" be adopted, a word strictly analogous to regelation already a familiar term in glaciology. Muller (1945, p. 21) uses "aggradation of permafrost" in the sense of pergelation as here proposed. For the thawing of pergelisol by natural or artificial means he uses "degradation of the permafrost" an idea which can easily be carried by de-pergelation.

Above the pergelisol lies a layer which thaws each summer and freezes each winter to a degree dependent on the march of temperature and the duration of the seasons. In this layer "frost-action" takes place and hence Muller calls it the "active layer." As thawing cannot occur without previous freezing, it is useless to argue as to which produces the greatest part of the activity involved. The annual thawing of this layer is its prime characteristic and it is consistent that the terminology emphasize this distinction from the pergelisol. In thawing there is usually produced more water than the volume of pore space so that the layer becomes soft and tends to flow. It may, therefore, be termed the "mollisol" from L. *mollere* to make softer, pliable, to melt, and sol=*solum*. The root of this word is familiar in emollient and other words. The act of thawing and softening may, if desirable, be known as "mollition."

The softening of the mollisol is its major characteristic although in well-drained ground where dry pergelisol occurs, melting produces no apparent softening. Whether such areas are large is not known and thus it is at present impossible to evaluate dry pergelisol. However, softening or "mollition" is the common activity and sets in motion the forces which result in congeliturbation. A fossil mollisol is a congeliturbate.

Muller points out that cool or short summers or very cold, long winters lead to failure to melt all the ground frozen the winter before. There thus intervenes between the mollisol and the pergelisol a layer of frozen ground which may persist for one or several years. For this layer he uses the Russian term "perelétok." Offhand there is no objection to adopting this Russian word but the pronunciation, which can be expressed more or less accurately by "pjerelyétok," is difficult. However, by the use of the prefix *inter*, among, between or amid, one can coin "intergelisol" which gives a term that will sufficiently

express the likeness of this material to pergelisol and also its situation between the top of the pergelisol and the mollisol.

Muller also introduces the Siberian word "talik" for bodies of unfrozen ground above, within, or below the pergelisol. This

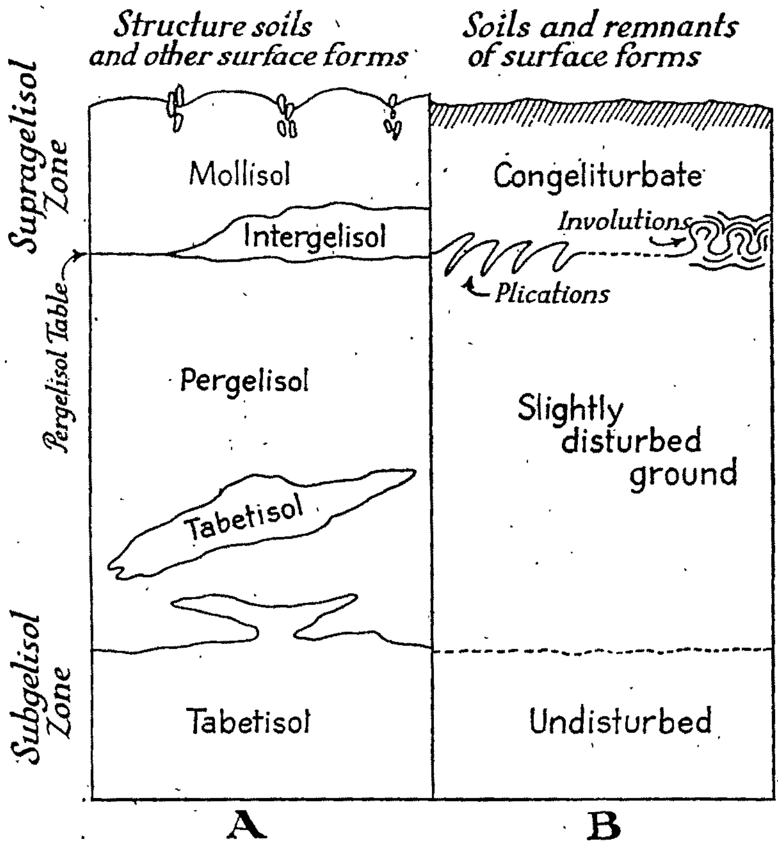

Fig. 4. Diagram showing terminology proposed: A. Characteristic parts of the ground in areas of permanently frozen ground; B. Characteristic parts of the ground in periglacial areas.

word has the merit of shortness and has only the handicap that it cannot easily be made into a verb. It appears that for various causes these areas of unfrozen ground are formed and again are refrozen. The production of "talik" is an idea that will doubtless be discussed and for which a term appears to be desirable. The new term "tabetisol" is here suggested from L. *tabescere,* to melt and sol=*solum.* The root is present in English in tabes, a wasting disease and tabetic, wasting, which is symp-

tomatic of tabes. The production of tabetisol would be expressed by the verb to "tabificate" and the verbal noun, "tabification."

The proposed terminology is parallel for present-day areas of intensive frost-action and for areas where this process was current in the past. The terminology is summarized in Fig. 4.

WIDESPREAD EROSION BY FROST-ACTION.

The idea that landscape can be molded by frost-action and that widespread and extensive reduction of elevation may occur in areas where frost-action is the dominant process is an old one. This idea is indicated by the "equiplanation" introduced by Cairnes (1912A). De Terra (1940) has discussed the problems of the Tibetan plateau and holds that the broad, smooth surfaces are largely the result of long-continued erosion by frost-action which varied in intensity during the Pleistocene fluctuations in climate. Many years ago, Wright (1910) called attention to the smooth upland surfaces of Iceland and southeastern Alaska above which rise peaks and below which deep glaciated gorges are cut. Noting that these uplands were lightly covered by glacial ice during the "ice flood" of the Pleistocene, he conceived of "ice-cap erosion" as an independent high-level process. If the ice covered these highlands only at the maximum of each ice advance, during the rest of the Pleistocene they must have been subject to frost-action with reduction in grade by congeliturbation of the surface accompanied by various forms of solifluction. The overrunning of these areas by ice is incidental, their reduction in slope is, however, as Wright presumed, due to processes unconnected with the fluvial-pluvial cycle of erosion.

Without much doubt Eakin (1916) had a similar idea concerning erosion in the Yukon Valley although his expression is confused. Cairnes (1912 A and B) believed that frost-action, rain-wash and solifluction operate on the relatively smooth and gentle slopes of the Yukon Plateau, but that the material thus eroded from the upperslopes is incorporated in frozen ground on the lower slopes. In this fashion the relief is lowered by erosion above and deposition below without loss of material to the area except through the activity of streams. This process he named "equiplanation." That the complex of processes in congeliturbation contribute the principal load to streams, and constitute the principal and, in many parts of the Arctic, the

sole agent of degradation was not part of Cairnes' concept. He seems to have ignored frost-action on the steep slopes of the canyons of eastward flowing streams which dissect the Yukon Plateau. However, Poser (1936) has clear-cut ideas on these matters. He points out that the rivers of East Greenland run only during the melting season. Their activity is closely related to the supply of detritus from the interfluves. The detritus consists of congelifracts of all sizes supplied by rain-wash and solifluction from rock slopes largely mantled by congeliturbates. The rivers carry off the fine congelifractate without difficulty but their broad beds are paved by large congelifracts which are only gradually reduced by congelifraction to sizes small enough to be transported.

These brief references, which might be much extended, indicate that in Arctic and high mountain lands reduction of the land may be largely due to intensive frost-action and concurrent action. Furthermore, similar processes were once at work in the periglacial region as emphasized by Soergel (1921) and others. The land forms are not analizable under the normal "Cycle of Erosion" of Davis. A new term seems necessary and an appropriate coinage would be "cryoplanation" from κρύος, icy cold or ice and plane, through French from L. *planus*, Greek, πλάτος broad. The term would be parallel to peneplanation although without implication that the process had reached or nearly reached completion. We would, however, be able to say that an area is or has been subject to the "Cycle of Cryoplanation" in contrast to areas subject to the "Pluvial-fluvial Cycle."

SUMMARY.

The foregoing suggestions as to terminology are somewhat overpowering in number. They are put forward with due apology and in the hope that these coinages will serve a useful purpose. Those familiar with the complications of Cryopedology will recognize that not all ideas, processes or materials are provided with names. The surface forms of congeliturbation are so numerous that it is doubtful whether Sharp's simplification will meet with unanimous approval. New ideas and interpretations are also in the making and an enlargement of the vocabulary here proposed is inevitable.

The new terms are summarized below:

Cryopedology = the science of intensive frost action and permanently frozen ground including studies of the processes and

their occurrence and also the engineering devices which may be invented to avoid or overcome difficulties induced by them.

Cryoplanation = land reduction by the processes of intensive frost-action, i. e., congeliturbation including solifluction and accompanying processes of translation of congelifracts. Includes the work of rivers and streams in transporting materials delivered by the above processes.

Congelifraction = frost-splitting or frost-riving.

Congelifract = the individual fragment produced by frost-splitting.

Congelifractate = a body of *congelifracts,* a mass of material of any grain size produced by congelifraction.

Congeliturbation = frost-action including frost-heaving and differential and mass movements. Includes solifluction, sludging, etc.

Congeliturbate = a body of material disturbed by frost-action = warp, trail, head, Coombe rock, Erdfliessen, Brödelerde, etc. These materials are characterized by surface forms: structure, soils, soil stripes, block-fields, mounds, etc. In places, structures characteristic of the surface forms are recognizable in the congeliturbate.

Pergelisol = permanently or perennially frozen ground = "tjäle" = "permafrost."

Pergelisol table = top of pergelisol.

Subgelisol = zone of unfrozen ground below permanently frozen ground.

Supragelisol = zone above the pergelisol.

Dry pergelisol = material having the requisite mean temperature to be permanently frozen but lacking water content or "dry."

Pergelation = the act or process of forming permanently frozen ground in the present or in the past.

De-pergelation = the act or process of thawing permanently frozen ground.

Mollisol = seasonally thawed ground above the pergelisol = "active layer" of Muller.

Mollition = the act or process of thawing the mollisol.

Intergelisol = perelétok, a layer of frozen ground between the pergelisol and the mollisol, which may persist for one or several years.

Tabetisol = talik, unfrozen ground above, within, or below the pergelisol.

Tabetification = the act or process of forming tabetisol.

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ABUNDANCE OF TUNGSTEN IN IGNEOUS ROCKS.

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OUR present knowledge of the tungsten content of igneous rocks is largely based on the results of an investigation by von Hevesy and Hobbie(1).* These authors, using an X-ray spectrographic method after preliminary chemical concentration of the element, found 69 parts per million of tungsten in a mixture of 282 central European igneous rocks of Caledonian and Variscian age(2), 83 p.p.m. in a specimen of granite (Schwarzwald), and 24 p.p.m. in a mixture of 67 gabbros and norites. The molybdenum content of these samples is also given. A few values for tungsten in rocks, comparable in magnitude with those of von Hevesy and Hobbie, were reported by I. and W. Noddack in connection with a study of the geochemistry of rhenium(3). They found 4, 30, and 20 p.p.m. of tungsten in granites from the Harz, Norway, and the Andes respectively; 20 p.p.m. in the lava of Vesuvius; 20 p.p.m. in basalt from Kaiserstuhl and 5 p.p.m. in basalt from Sweden; and 3 p.p.m. in kimberlite. In addition, the tungsten (and molybdenum) contents of many minerals are stated. Details regarding the methods of concentration and determination of the traces of tungsten and other elements are not given, but presumably the final determination was made by X-ray spectrography. It is stated that the results may be in error by ± 25 per cent in general.

The above values for tungsten in igneous rocks are higher than might be expected and it seemed desirable to determine the element by a different method in a series of composite samples. Further work on the abundance of tungsten appeared necessary also because von Hevesy and Hobbie's figures for the amount of molybdenum in igneous rocks do not agree well with the values found for a series of American rocks(4), the respective average contents being 15 and approximately 2.5 p.p.m.

METHOD OF ANALYSIS.

The procedure used in determining tungsten in silicate rocks is described in detail elsewhere(5). In brief the method is the

* Numbers in parentheses indicate the references at the end of the article.

following. The sample (0.8 to 1.0 gram) is decomposed with hydrofluoric, sulfuric, and nitric acids. Iron, titanium, and some other elements are removed by double precipitation with excess sodium hydroxide. Molybdenum is then precipitated as the sulfide, antimonic sulfide being used as a collector. Tungsten is determined colorimetrically in the final solution by adding thiocyanate, excess hydrochloric acid, and stannous chloride to form a yellow thiocyanate complex of tungsten in a lower valence state, which is extracted with ether. The color of the ether is compared against standards in small tubes having a cross-sectional area of approximately 1 square centimeter. It is possible to detect 0.5 p.p.m. of tungsten with certainty when a 1-gram sample is taken.

The method was tested on natural and synthetic rock samples to which known amounts of tungsten were added. The best results are obtained with silicic rocks in which the percentages of iron and titanium are low. As the amounts of the latter increase, the recovery of tungsten progressively decreases. Useful results (approximately 80 per cent recovery of tungsten) can still be obtained with a rock containing 6 per cent total iron oxides, 0.9 per cent TiO_2, 3 per cent MgO, 5 or 6 per cent CaO, and 0.25 per cent P_2O_5. Approximately one-half of the added tungsten (a few parts per million) is recovered from a sample containing 13 per cent total iron oxides and 1.75 per cent of TiO_2; the remainder of the tungsten is lost by coprecipitation in the precipitate produced by sodium hydroxide, especially in the hydroxides of titanium and iron. The method cannot, therefore, be applied to a typical basic rock, except perhaps for the purpose of obtaining a rough value for the amount of tungsten present. In general, the method is applicable to rocks in the silica range above 60 per cent.

With the exception of vanadium, no element is known, which in amounts likely to be encountered in igneous rocks, will yield a color similar to tungsten under the conditions of the determination. Vanadium produces a color approximately 1/300 as strong as an equal weight of tungsten. In other words a sample containing 0.015 per cent V (0.022 per cent V_2O_3) would show an apparent tungsten content of 0.5 p.p.m. In silicic rocks for which the method is primarily intended the vanadium content will be less than this and the effect of this element can be disregarded. Even in intermediate rocks with a silica percentage greater than 60, it is unlikely that this value for vanadium

will be exceeded. If necessary the vanadium content of the sample can be found by a simple colorimetric method and the requisite amount of vanadium can then be added to the colorimetric standards in the tungsten determination.

SAMPLES.

Most of the samples analyzed were composites of plutonic rocks. The composites were prepared on the basis of silica content for the most part. In order to see whether there might be a regional factor involved in the distribution of tungsten, several composites having similar silica ranges (average about 72 per cent) were made up from granites from Canada, New York state, Minnesota, and Africa respectively. The results of the analyses of the composites are given in Table I.

TABLE I.

Tungsten in Composites of Igneous Rocks.

Silica Range % SiO_2	Average Silica % SiO_2	Type of Rock	No. of Samples	Region	Tungsten P. p. m. W
81.5–75.1	77.4	Granite*	20	Various†	2.0
77.4–71.5	74.1	‡	9	California	1.4
76.8–68.2	73.1	Granite	5	Texas (Llano region)	1.8§
74.3–70.6	72.6	Granite	7	Canada	1.4
73.9–70.0	72.0	Granite	9	Africa	1.3
73.3–70.7	72.0	Granite	6	New York	1.0
....	...	Granite	5	Minnesota	1.1
69.6–65.5	68.4	¶	14	‖	1.3
66.4–64.8	65.6	Quartz monzonite	2	California	1.6
65.7–52.7	62.0	Diorite	7	Oregon and California	1.2
64.1–56.0	60.3	Syenite	6	New York and Minnesota	1.9Δ

* Includes 1 quartz porphyry, 1 quartz monzonite.

† Origin as follows: Canada 3, New York 5, Texas 3, 8 from unspecified U. S. or Canadian localities, Africa 1.

‡ 4 granites, 2 quartz monzonites, 1 monzonite, 2 granodiorites.

§ Average of separate determinations, Table II; analysis of a composite sample gave 2.0 p.p.m. W.

¶ 6 granites, 1 granite porphyry, 1 felsite porphyry, 1 porphyry, 1 quartz monzonite, 1 granodiorite, 1 diorite. 2 dacites.

‖ Canada 2, New York 1, Texas 2, Montana 2, Wyoming 1, California 2, 4 from unspecified U. S. or Canadian localities.

Δ Not corrected for vanadium which may be present in appreciable amount so that true value for tungsten may be slightly lower.

Five granitic rocks from the Llanó region of Texas (6) were analyzed individually (Table II). In addition a rhyolite from

Cook County, Minnesota, was found to contain 2.4 p.p.m. of tungsten.

The values for tungsten have been recorded to 0.1 p.p.m., but in comparing results it should be borne in mind that an error of 0.2 or 0.3 p.p.m. is possible in comparing colors. To this must be added any systematic errors of the method. For rocks with more than 70 per cent silica the results are believed to be essentially correct as judged by the recovery of tungsten added to known samples, but as already stated the values may be slightly low with the less silicic samples. Basic rocks which are definitely known to give low results for tungsten by the method applied have not been analyzed.

TABLE II.

Tungsten in Silicic Rocks of the Llano Region, Texas.

	SiO_2 %	W P.p.m.
Granite, Bear Mountain	76.8	2.4
Granite porphyry (llanite)	75.2	2.6
Granite, Granite Mountain	73.0	1.6
Granite, Cassaday	72.2	1.5
Granite, Town Mountain	68.2	1.1

DISCUSSION.

The results obtained point to an average tungsten content of approximately 1.5 p.p.m. for silicic and intermediate igneous rocks (silica range 80 to 60 per cent). In general it appears that the amount of tungsten in an igneous rock increases with the silica content. This trend is quite clear in the case of the Texas granites which have a common origin. The parallelism is less regular, as might be expected, but still perceptible, in the composites.

It seems natural to correlate tungsten, as an acidic element, with silica in igneous rocks. The ionic radius of hexavalent tungsten is small, probably being slightly less than 0.5 A. With the exception of silicon, all the major elements of the magma have ionic radii greater than this value, the radius of silicon equalling 0.39 A. (The next largest ion, aluminum, has a radius of 0.57 A according to Goldschmidt.) Because of the magnitude of the difference in the radii of tungsten and silicon it may be supposed that tungsten will have relatively little tendency to separate with the early crystallizing silicates and that, therefore, it will be concentrated in the residual liquid as the magma

crystallizes. However, the concentration of tungsten in the silicic rocks does not appear to be very striking. The present method unfortunately does not allow the partition coefficient of tungsten between acidic and basic rocks to be determined. It may be noted that von Hevesy and Hobbie found about one-third as much tungsten in the basic rocks (gabbros and norites) as in their igneous rocks as a whole. The behavior of tungsten is similar to that of molybdenum, so far as rather scanty data indicate, which is to be expected from the similar ionic radii of hexavalent tungsten and molybdenum. A thorough study of the distribution of tungsten in silicate rocks must await the development of a better analytical method than any now available, whether spectrographic or chemical.

There is no evidence of any significant regional variation in the tungsten content of the rocks examined. Although the data are insufficient to allow any positive statement to be made, there is no indication of a radical difference in the tungsten contents of pre-Cambrian and later silicic rocks (California composite).

The results obtained permit a rough estimate of the tungsten content of the upper lithosphere. The maximum content is not likely to exceed greatly the value 1.5 p.p.m. found for the silicic and intermediate rocks analyzed. Although the total number of samples examined is comparatively small, the general similarity of the tungsten values found for rocks from different areas lends considerable support to the belief that the upper limit cannot be far from this value. It would be surprising if another series of plutonic rocks should give a value of 10 p.p.m., or even 5 p.p.m. There is thus a large discrepancy between von Hevesy and Hobbie's value for igneous rocks as a whole (69 p.p.m.) and the present value for rocks with a silica range of 60 to 80 per cent. The lower limit for the relative amount of tungsten in the lithosphere cannot be fixed very exactly on the basis of the results obtained in the present work. If it is assumed that rocks with silica content less than 60 per cent contain no tungsten and that these rocks compose as much as one-half of the lithosphere, the average would be 0.75 p.p.m. of tungsten. But there must be some tungsten in the less silicic rocks, so that the average value for the upper lithosphere must be greater than this. We may accordingly take 1 p.p.m. as the most likely tungsten content of igneous rocks as a whole on the basis of the results here reported. If this value for tungsten is accepted as

being not far from the truth, it follows that tungsten is one of the least abundant elements of the crust of the earth. It would then be scarcer than beryllium (6 p.p.m.), scandium (5 p.p.m.), arsenic (5 p.p.m.), cesium (7 p.p.m.) as well as most of the rare earths, if the figures for these elements are substantially correct (7). The question whether tungsten or molybdenum is more abundant in igneous rocks cannot be answered definitely at the present time. Analysis of a relatively small number of samples from various areas of the United States gave an average value of 2.3 p.p.m. of molybdenum, silicic and subsilicic rocks being weighted equally (4). This figure may be too high. At any rate the relative amounts of tungsten and molybdenum in the upper lithosphere are not greatly different.

ACKNOWLEDGMENTS.

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SOME OBSERVATIONS ON CHROMITE.[1]

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ABSTRACT. Evidence is presented showing that some of the chromite concentrations occurring in a serpentinized ultrabasic mass were emplaced after the ultrabasic rocks had solidified and could fracture. Specimens of "grape-ores" show euhedral crystals of olivine surrounded by nodules of chromite and not altered to serpentine: in that case the olivine crystallized before chromite. Serpentinization and calcite veining have altered or replaced chromite.

DURING the summers of 1942 and 1944 the writer mapped the east half of Orford area, in the Eastern Townships of Quebec, and gave some time to the study of the chromite deposits there. The deposits, which were mined during both World Wars, are found in a large mass of serpentine between Brompton and Webster lakes, some 12 miles north of the north end of Lake Memphremagog.

The chromite bodies are mainly confined to a zone about half a mile wide and 4 miles long. Chromite has been mined from some 20 pits, and more than 40 other occurrences are known and have been studied (Text Fig. 1). The chromite bodies may consist of massive chromite, of grains disseminated in serpentine, or, commonly, of both types. In shape they form lenses, pods, vein-like bands, and irregular patches. Their dip is generally steep, but there is no uniformity of strike. Parallelism either with the trend of the zone or with the edge of the serpentine mass is exceptional. However, it must be kept in mind that the contact is mapped from scattered exposures and was not actually observed.

The data obtained yield some interesting information on the precise age of the chromite, relative to the rest of the rock. One locality also afforded some facts bearing on the alteration and replacement of chromite.

Table I shows that the chromite occurrences are found generally in what was identified as serpentinized dunite. Only one instance was observed where a low concentration of chromite

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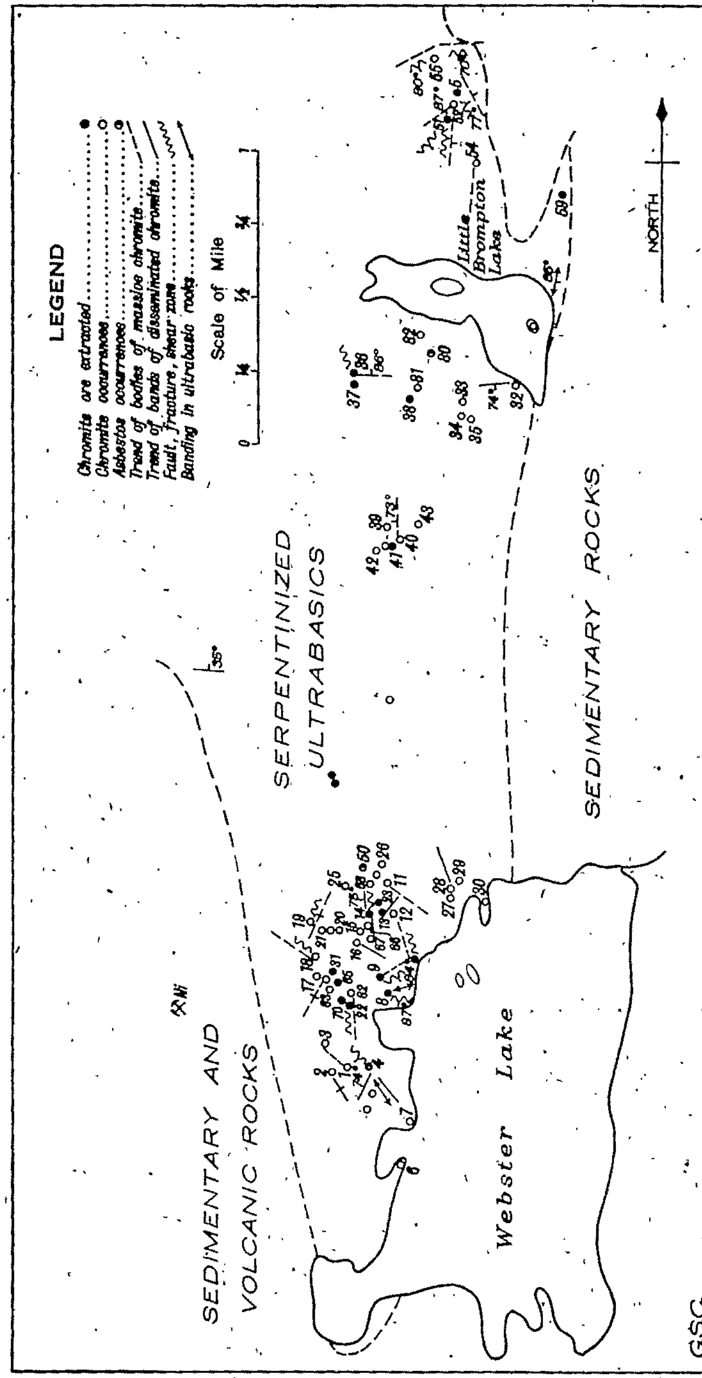

LEGEND
Chromite are extracted
Chromite occurrences
Asbestos occurrences
Trend of bodies of massive chromite
Trend of bands of disseminated chromite
Fault, fracture, shear zone
Banding in ultrabasic rocks
Scale of Mile
SERPENTINIZED ULTRABASICS
SEDIMENTARY AND VOLCANIC ROCKS
SEDIMENTARY ROCKS
Webster Lake
Little Brompton Lake
NORTH
GSC

Text Fig. 1.

is present in peridotite. Such constant association implies that most of the chromium ore was concentrated during the magmatic stage of the ultrabasic intrusion. The conclusion is further confirmed by the occurrence of much chromite in disseminated form, in a matrix of serpentine which presumably was originally olivine. The disseminated material commonly occurs in bands an inch or less in thickness, alternating with bands of serpentine that carry no chromite, of about the same thickness. Although the banding has never been adequately explained, it would seem to be an original magmatic structure. In occurrence 31, diagrammed in Text Figure 2, a band of disseminated chromite is curved and broken, suggesting movement within the magmatic mass in the crystal-mush stage. Even the bodies of massive chromite occasionally parallel the banding, as in occurrence 17 (Text Fig. 2).

The shapes of many of the chromite bodies are most peculiar, as for example those of occurrences 6, 39, 54, and 80 (Text Figs. 1 and 2). It is difficult to reconcile such forms with any hypothesis of differential crystal settling in a quiet medium.

Plate IA shows a thin section of "grape ore" from occurrence 9, Text Figure 1. The section shows one euhedral grain of fresh olivine embedded in massive chromite, and two pseudomorphs of antigorite after euhedral grains of olivine in chromite that has been fractured so as to permit access of serpentinizing solutions. Obviously, crystallization of olivine was well advanced before crystallization of chromite began. H. H. Hess (1933) and H. C. Cooke (1937) have shown that serpentinization took place, in all probability, through the action of magmatic water in the closing stages of consolidation of the rock. If they are correct, the chromite of this section must have formed in the relatively brief period after much of the olivine crystallized, but before serpentinization began.

Plate IB, a photograph of a specimen from occurrence 11, shows massive chromite cut by a vein of chrysotile asbestos. In another place, the writer found massive chromite cut by a veinlet of antigorite. The asbestos and the antigorite may belong to the period of general serpentinization, like the serpentine filling the small cracks in the specimen figured in Plate IA.

In a number of places chromite is deposited along well-defined fissures. Such for example are occurrences 18, 56, and 80, diagrammed in Text Figure 2. In these drawings, the thin black lines represent the fissures where they contain no chromite.

TABLE I.—Some Observations on Chromite Occurrences.

Occurrences	Chromite Grains		Chromite & Country Rock		Chromite & Shears, Fractures		
(numbers refer to Text Fig. 1)	Massive chromite in lenticular, wedge-shape tabular bodies	Banded disseminated chromite	Country rock	Chromite parallel to banding in country rock	Presence of shear zone or fractures	Chromite in or parallel to fractures	Chromite not related to fractures
2	x	x			x		Chromite is brecciated
4	En echelon			x	x		
5	x	x	Dunite		x	x	
1			Serpentine		x	?	
11	x		Dunite?		x		x
13			Dunite		x	x	
14			Dunite Peridotite		x	x	
15			Dunite				
16	x	x					
17			Dunite	x	Brecciation		
18	x		Dunite		x	x	
19	x		Dunite			x	
22	x	x	Dunite cut by pyroxenite				
23			Dunite?	x			

26	x		Dunite		x		Chromite is slickensided
27			Chromite cut by pyroxenite				
28		x	Dunite		x		Chromite reported to branch
30	Coarse grain	x	Dunite	x	x		Chromite is faulted
31	x	Coarse xline	Dunite		x		
35			Dunite peridotite nearby				
36	x		Serpentinized dunite		Serpentine slickensided	x	Chromite fractured
38			Dunite				
39	Vein-like bodies		Serpentine				
40	Patches of massive chromite						
51	Zone 2 feet wide		Serpentinized dunite		Two sets of shears	x	
52	Small pockets in two parallel zones		Serpentinized dunite				x
53		x			x	?	
54	x		Dunite?		x	?	
55					x	x	x
56	Massive band		Dunite		x	x	

Some fissures have slickensided walls, indicating some fault movement, others appear to be merely joints. In the occurrences figured, the chromite does not appear merely to have filled pre-existing fissures, as described by Cooke in Thetford area (1937, pp. 146-7), but seems to have replaced one or both walls of the fissure to form plate-like or pod-like masses. The ore of these masses is solid chromite with sharp, almost knife-edge boundaries against the serpentine. It would seem, then, that some chromite at least did not crystallize until the general mass of the rock was solid enough to fracture.

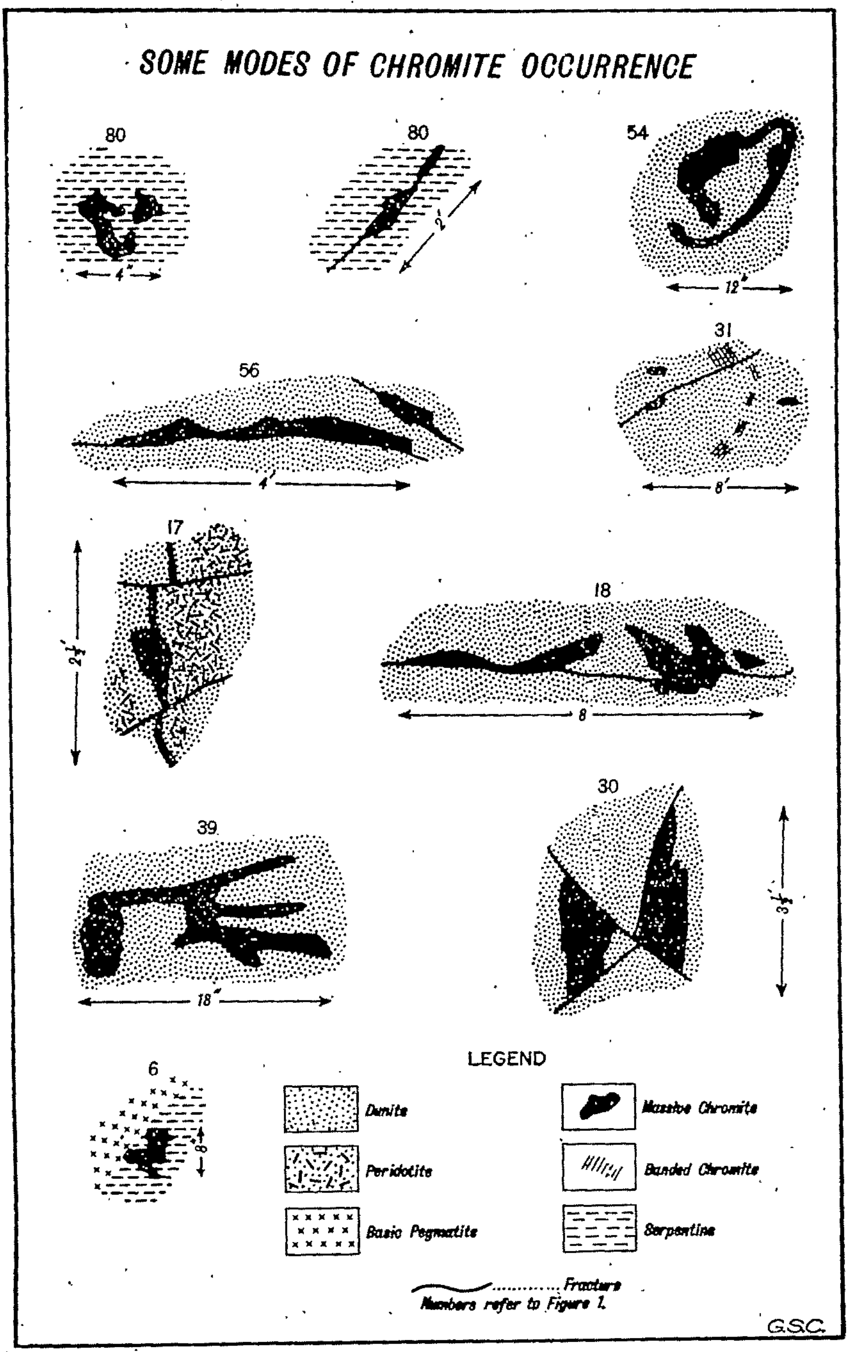
Finally, in two instances (occurrences 22 and 27) chromite masses are cut by dykes of pyroxenite; and, in occurrence 6, by a sort of pegmatite that seems to be a phase of the pyroxenite. Of such dykes Cooke says, (1937, p. 66) "The pyroxenite dykes that cut the peridotites and the mixtures of pyroxenite and pyroxene-rich peridotite indicate that pyroxene-forming magma remained fluid after consolidation of these rocks. Many of the dykes are so narrow, and their grain is so coarse, that by no stretch of imagination can they be supposed to have been formed by injection of material already crystalline in large part, as Bowen's hypothesis would have it. Any such attempt would inevitably have resulted in the crystals jamming and blocking the narrow fissures." The fact that such dykes cut the chromite bodies also, is additional evidence of the position of chromite in the magmatic cycle.

The facts cited would appear to justify the following conclusions:

a) That most of the chromite of the parent magma separated out, along with the olivine constituents, to form the dunite bodies.

b) That olivine crystallized, in part at least, before the chromite. Some chromite was entangled between the grains of olivine to form the disseminated ores. The remainder, collecting in larger or smaller fluid masses, formed the well-known "grape ore," or, impelled perhaps by stresses within the still partially fluid magma, took on the irregular and vaguely vein-like shapes indicated in Text Figure 2, and more particularly in occurrences 89 and 54.

c) That some of the chromite, at least, remained fluid until the body of the rock was solid enough to fracture. Some of the fluid then entered the fractures to form plate-like and pod-like masses.


SOME MODES OF CHROMITE OCCURRENCE
80
4"
80
2'
54
12"
56
4'
31
8'
17
2½'
18
8
39
18"
30
3½'
6
8"
LEGEND
Dunite
Peridotite
Basic Pegmatite
Massive Chromite
Banded Chromite
Serpentine
Fracture
Numbers refer to Figure 1.
G.S.C.

Text Fig. 2.

d) That all of the chromite was c liquid remnants of the magma flowe pyroxenite dykes.

* * * *

Chromite, in spite of its refracto nary laboratory reagents at low t nature by serpentinization and calcit

A specimen of serpentinized perido ster Lake consists mainly of felted a of talc. It carries dissected grains thin rims of isotropic, highly refring ably chrome garnet, and veined birefringence.

In a thin section of dunite from Mı of chromite have fringed peripheries. the chromite was attacked and some process of serpentinization; or that the chromite when the olivine was se

Dunite from the south shore of brown grains of chromite with alm periphery and along fractures. Or has a peripheral skeleton of blackish antigorite; the blackish material als into the body of the chromite grain. blackish parts are light gray wherea gray with a brownish tone. The d along edges and fractures suggest probably iron, during the process of

Alteration of chromite by solutic vein was studied at the old nickel mir the Orford Nickel and Copper Comp three-quarters of a mile west of Wel lies at the contact of a serpentine s It is a calcite vein some 9 feet wide, vegetation and slumping, but still t feet. The ore, which consisted of ma completely mined out that none was f minerals present are small masses with cores of chromite.

Besides the main vein, there are nı of calcite in the serpentine near by.

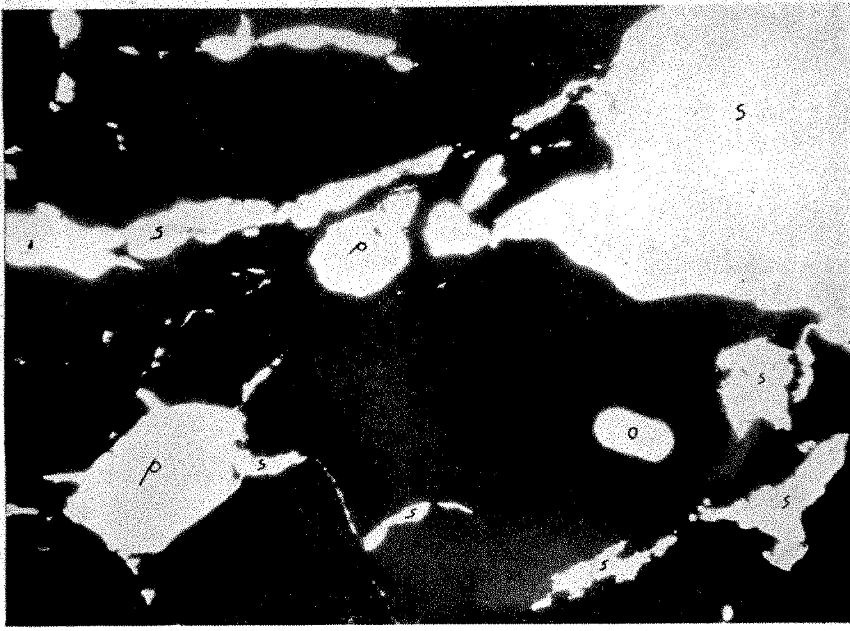
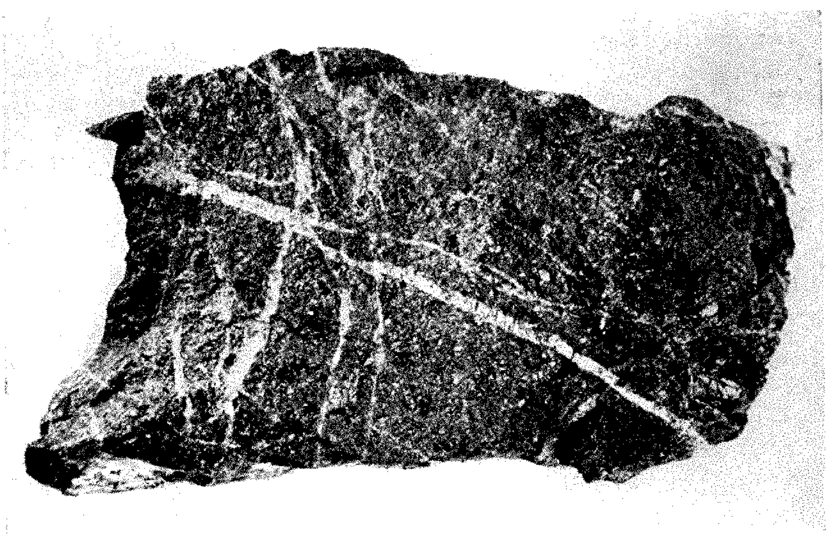
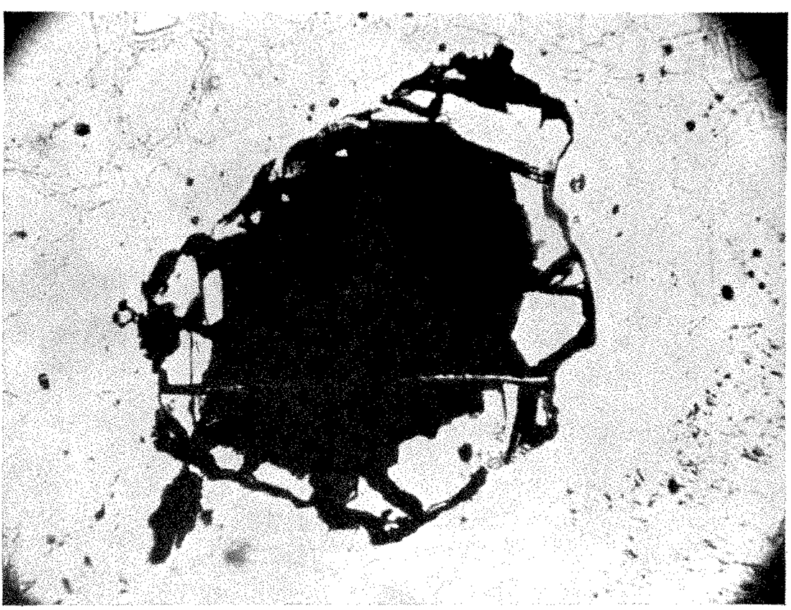


Plate 1. A. Euhedral grain of fresh olivine (o) surrounded by massive chromite (black). Antigorite pseudomorphs after olivine (p) surrounded by chromite with fractures. Serpentine (s). x 50.



B. Massive chromite cut by vein of chrysotile, from occurrence 11, Text fig. 1. Natural size.

Plate 2. A. Serpentinized dunite with chromite grains, Mud Pond. The fringed edges of the chromite grains may be due to replacement of serpentine by chromite or vice versa, or to addition of iron to the chromite when the olivine was serpentinized. x 48.



B. Chromite in serpentinized dunite. The main body of the grain is dark brown. It is traversed by black lines that extend into the surrounding serpentine to form a peripheral skeleton. The blackening may be caused by enrichment in iron oxide. x 206.

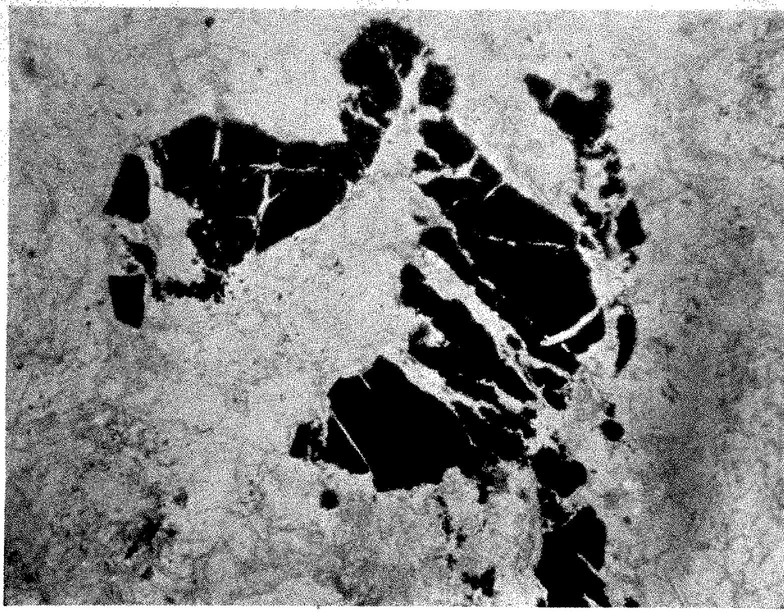
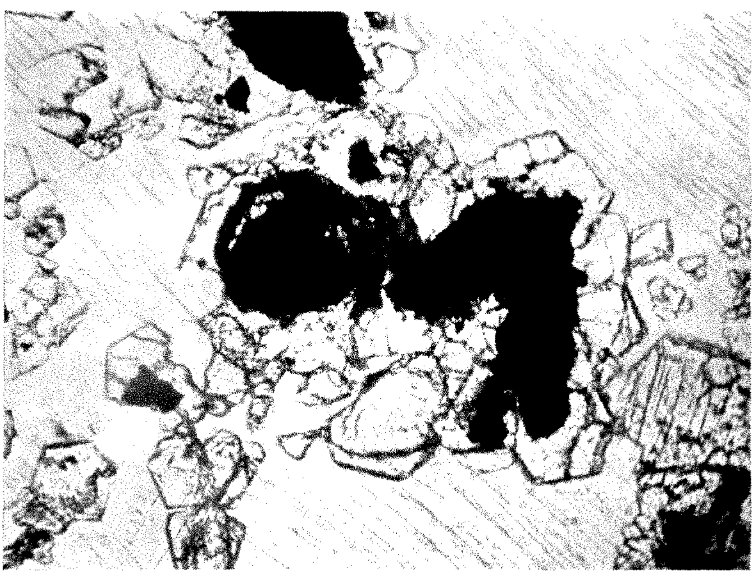


Plate 3. A. Dissected patch of chromite with fringed, darkened peripheries. The chromite is veined and apparently replaced by calcite. x 48.



B. Dark brown cores of chromite with darker, fuzzy, fringed peripheries in uvarovite (high relief) lying in calcite (striated by grinding). One grain of diopside along right-hand edge of photograph shows cleavage and high relief. x 46.

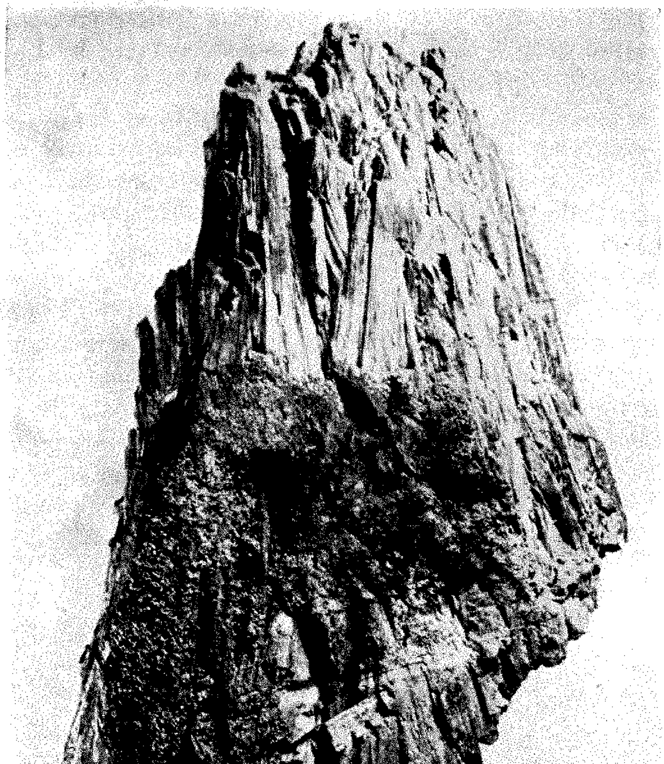


Plate 4. Long prisms of diopside with patch of fine crystals of uvarovite, from the old "Nickel mine." Natural size.

forming solutions penetrated the serpentine along various cracks and openings, and replaced it readily. One of these patches includes remnants of massive chromite and serpentine.

One of the chromite remnants in this patch is shown in Plate 3A. Inspection of this plate can leave little doubt that the chromite has been in part dissolved and replaced by the solutions depositing the calcite.

The main vein, which follows the contact of the serpentine and quartzose schist, is rather different, apparently because the solutions were able to take up silica from the quartzose wall, as well as to dissolve serpentine from the other wall. One result was the formation of a good deal of diopside, which crystallized in aggregates of elongated prisms up to 6 inches long on the walls, and in thick plates within the vein. The point of more direct interest is, however, the action on chromite, of which a number of remnants were found, the largest about a foot long. These were vigorously attacked, and converted into the chrome garnet, uvarovite ($3CaO.Cr_2O_3.3SiO_2$). When aggregates of uvarovite crystals are broken open, cores of chromite are found in most of them (Plate 3B). The edges of the cores are fuzzy and fringed.

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GEOLOGICAL SURVEY, CANADA,
OTTAWA, CANADA.

REDEFINITION OF ACTINOCRINUS PARVUS SHUMARD.

EDWIN KIRK.[1]

ABSTRACT. In 1855, Shumard described a crinoid from the St. Louis limestone at St. Louis, Missouri, as *Actinocrinus parvus*. In 1881, Wachsmuth and Springer through inadvertence applied this name to a common and characteristic crinoid of the upper part of the Burlington limestone ("Upper Burlington"). This usage has been followed by authors generally, the species being currently known as *Aorocrinus parvus*. Shumard's species is here referred to *Dizygocrinus*, and Hall's species *Actinocrinus symmetricus* is revived for the Burlington crinoid, which now stands as *Aorocrinus symmetricus* (Hall), new combination.

IN his original description of *Actinocrinus parvus*, Shumard (1855, p. 193) states "we possess only a fragment of the body"; "anal pieces unknown"; "situation of the proboscis is unknown"; "general form is globose." The plates of the dorsal cup are "ornamented with very fine, somewhat flexuous striae, which radiate from the center of each piece [plate] to the sides, where they unite with striae from the adjacent pieces in such a manner as to form several series of isosceles triangles around the body; the plates are thick and very finely serrated at the sutures." In size he gives the over-all height of the theca as 5 lines [10.6 millimeters]; maximum diameter 5 lines [10.6 millimeters]; and height of dorsal cup 3 lines [6.3 millimeters]. The horizon and locality is given as "St. Louis [Missouri], in the upper part of the St. Louis Limestone, associated with *Palaechinus* [*Melonechinus*] *multipora*, and *Poteriocrinus longidactylus*. It is very rare."

Until 1881 *Actinocrinus parvus* was quoted as such and given a St. Louis age, as may be seen in various bibliographic citations. Wachsmuth and Springer (1881, p. 179) referred the species to *Dorycrinus* and state "Upper Burlington limest. (not St. Louis limest. as quoted by Shumard), Palmyra, Mo. and Burlington, Iowa." It is certain that Wachsmuth and Springer had not seen Shumard's specimen and had no further knowledge of the species than was to be had in Shumard's publication. The reference to *Dorycrinus* and the identification of the species with the common Burlington form was undoubtedly a case of misidentification.

[1] Published with the permission of the Director, Geological Survey, United States Department of the Interior.

There seems to be no valid reason for doubting Shumard's attribution of "*Actinocrinus*" *parvus* to the upper part of the St. Louis limestone at St. Louis, Missouri. No one has known the St. Louis limestone better than he, and he was not the type of man given to factual errors. Furthermore, the reiteration of the horizon and locality as given by him in his carefully compiled catalog (1865, p. 346) gives added confirmation, if such were needed.

In his purchase of the Hambach collection Springer acquired at least two of Shumard's types figured in the Missouri report, *Steganocrinus concinnus* and *Dorycrinus missouriensis*. In an attempt to discover further types, he identified a small *Aorocrinus* of the species commonly known as *Aorocrinus parvus* as the type of Shumard's *Actinocrinus parvus*. This identification is undoubtedly incorrect. The size of the specimen, allowing for variations in measurement, is about right. The height of the dorsal cup is relatively greater than in Shumard's specimen, however, as it is in all conspecific specimens. The specimen is a complete, uncrushed theca. It is partially silicified, and the original surface is destroyed. It is obvious from the excerpts of Shumard's description given above that this could not possibly be the specimen Shumard had in hand.

There can be little doubt as to the generic placement of "*Actinocrinus*" *parvus*, considering the geologic age of the species. The general form of theca and the relative proportions of cup and tegmen, together with the surface ornamentation, indicate *Dizygocrinus*. The surface ornamentation alone, as described by Shumard should have stopped Wachsmuth and Springer from making the identification they did. Shumard's species will therefore stand as *Dizygocrinus parvus* (Shumard), new combination. As noted in the abstract, Hall's species *Actinocrinus symmetricus* is revived for the reception of the Burlington species that has commonly been called *Aorocrinus parvus*. The species is referred to *Aorocrinus* and the species will now stand as *Aorocrinus symmetricus* (Hall), new combination. The following citations will correct the synonymy:

Dizygocrinus parvus (Shumard), new combination.

Actinocrinus parvus Shumard 1855, p. 193, Pl. A, Fig. 8.

"At St. Louis, in the upper part of the St. Louis Limestone, associated with *Palaechinus multipora*, and *Poteriocrinus longidactylus*." (St. Louis limestone.)

Actinocrinus parvus Shumard 1865, p. 346.

Actinocrinus parvus Miller 1877, p. 67.

Non Dorycrinus or *Aorocrinus parvus* of authors generally.

Aorocrinus symmetricus (Hall), new combination.

Actinocrinus symmetricus Hall 1858, p. 574, Pl. 10, Figs. 8a, b.

"Burlington limestone: Burlington, Iowa." ("Upper Burlington" limestone.)

Actinocrinus symmetricus Shumard 1865, p. 348.

Dorycrinus symmetricus Miller 1877, p. 77.

Dorycrinus symmetricus Miller 1889, p. 241.

Synonymy.—

Dorycrinus amoenus Miller 1891, p. 35, Pl. 5, Figs. 5, 6.

"Burlington group, Sedalia, Missouri."

Dorycrinus parvus Wachsmuth and Springer (*non* Shumard) 1881, p. 179 (353).

Dorycrinus parvus Miller (*non* Shumard) 1889, p. 241.

Dorycrinus parvus Keyes (*non* Shumard) 1894, p. 171.

Aorocrinus parvus Wachsmuth and Springer (*non* Shumard) 1897, p. 477, Pl. 45, Figs. 11a, b.

Aorocrinus parvus Bassler and Moodey (*non* Shumard) 1943, p. 305.

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Hall, James: 1858. Palaeontology. Iowa Geol. Survey Rept., 1, pt. 2, 473-724; index, 1-3; explanation of plates, 1-30; pls. 1-29.

Keyes, C. R.: 1894. Paleontology of Missouri. Part 1. Missouri Geol. Survey, 4, 89-271, pls. 11-33.

Miller, S. A.: 1877. The American Palaeozoic fossils: a catalogue of the genera and species, with names of authors . . . , etc. i-xv, 1-246. Cincinnati, Ohio.

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Wachsmuth, Charles, and Springer, Frank: 1881. Revision of the Palaeocrinoidea. Pt. 2, 1-237 and unnumbered explanations of plates, pls. 17-19. Acad. Nat. Sci. Philadelphia Proc. 1881, 177-414, pls. 17-19. Sept.-Dec. 1881.

————: 1897. Mem. Mus. Comp. Zool., 20-21, 1-837, 83 pls.

U. S. NATIONAL MUSEUM,
WASHINGTON, D. C.

SCIENTIFIC INTELLIGENCE

Physics and Chemistry.

Introduction to Atomic Physics; by Henry Semat. Pp. xi, 412; 169 figs. New York, 1946 (Rinehart and Co., $14.50).—A revision of a book published in 1939. Its outstanding feature is the thorough treatment of recent developments in nuclear physics. It is suitable as a text in junior and senior courses and contains enough material for approximately one semester's work.

The topics have been selected with a view toward the book's climax, nuclear reactions. For this reason, the author has been forced to treat lightly many of the more classical aspects of atomic physics. Thus optics and spectroscopy are discussed very briefly, and kinetic theory is almost wholly omitted. Clear diagrams enhance the usefulness of the book, and the exposition is lucid throughout.

In this reviewer's opinion, the book would appeal to a wider audience if fundamental theory had been given a more prominent place in the discussion of modern problems. HENRY MARGENAU.

Atomic Energy in Cosmos and Human Life; by G. Gamow. Pp. x, 161; 46 figs. New York, 1946 (The Macmillan Co., $3.00), Cambridge (The University Press).—This book is more informative than many of the popular treatments on atomic energy that have recently appeared. Written by a man who is known in the world of physics for his contributions to the theory of atomic nuclei and admired by many for his skill of exposition ("Mr. Tompkins in Wonderland," etc.), the material compressed into these 161 pages is authoritative, newsworthy, and full of throbbing life. There is nothing superficial in the treatment, and the layman will have to pay attention in order to follow the discourse. But to do so is not burdensome because of an abundance of illustrations, and it is highly rewarding.

The outlook of the book is not limited to the problems of the bomb. To this reviewer the most illuminating and satisfying part of its contents is the middle, where Gamow encompasses the whole range of questions concerning the release of energy and develops an ingenious theory of stellar evolution.

There is a thought-provoking foreword by Henry Norris Russell.

HENRY MARGENAU.

What Are Cosmic Rays?; by Pierre Auger. Translated by M. M. Shapiro. Pp. vii, 128; 22 plates. Chicago, 1944 (The University of Chicago Press, $2.00).—This book is an excellent résumé of a

fascinating subject, written by an authoritative author primarily for the non-physicist. It traces the historical development of the knowledge of cosmic rays from its early beginning to the present day and leaves the reader in a state of agitation in which he will spare no pains to see how the unsolved problems come out. The chapter headings are indicative of the author's approach and style: Story of a Discovery; The Heroic Epoch; Showers, Pairs, Bursts, Stars; Time Takes its Toll of Cosmic Rays; The Sky's the Limit.

The plates at the end of the book are beautiful, selected with care to convey the author's story. On finishing the book one wonders whether its success is altogether due to the author's skill, or whether the subject has an innate appeal which makes its treatment so satisfying. HENRY MARGENAU.

Chemical Machinery; by E. R. RIEGEL. Pp. ix, 588; 487 figs. New York, 1944 (Reinhold Publishing Co., $5.00).—The practicing engineer should find this book useful as a guide to the great variety of equipment for the process industries. The twenty-seven chapters may be divided roughly into groups treating the following subjects: The handling of solids, liquids and gases; storage; agitation and mixing; the separation and purification of materials; heat exchange and refrigeration; high pressure equipment; and instruments. The book is well-organized, and the illustrations are good. The index is adequate. The author describes and compares a sufficient variety of types of equipment for any given requirement to permit the reader to make a wise choice among such types. Extensive operating and performance data are given.

The illustrative examples are in many cases so pre-digested as to amount to mere instructions for the use of accompanying tables or nomographs. This reviewer feels that in such a book, primarily descriptive in nature, such examples might well be omitted.

HARDING BLISS.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Animal Cytology and Evolution; by M. J. D. WHITE, Pp. xiii, 375; 121 figs. New York, 1945 (Cambridge University Press, $7.50).—The union of cytology and genetics has produced an offspring, cytogenetics, which has shown most of the features of heterosis. As a result the offspring has preëmpted so much attention that some have been inclined to forget the parents entirely, especially the parent cytology. The enormous advances made by cytogenetics, particularly with regard to chromosome structures, mechanics, and rearrangement, since the last edition (1925) of Wilson's "Cell" have made a review and restatement of the evolu-

tionary aspects of cytology imperative. While the bearings of plant cytogenetics on evolutionary problems have been stressed in recent times, particularly by Darlington and others, the contributions of animal cytogenetics, outside the sphere of *Drosophila,* have received scant attention. It is the great merit of Doctor White's book to incorporate the theoretical contributions of cytogenetics to cytology as the foundation on which to deal with the relations between animal cytology and evolution. The first chapters of the work are therefore introductory.

The main body of the work begins with a treatment of chromosomal evolution in wild populations summarizing the literature exclusive of *Drosophila,* chiefly on Orthoptera. An entire chapter is devoted to chromosomal evolution in the genus *Drosophila* which provides us with the most complete and detailed examples of genic and structural differences between taxonomic categories. The combined works of many investigators have given ample evidence that within the sub-genus *Sophophora* the basic chromosomal material is much the same in terms of chromosome arms, that most of the structural changes have been either within chromosome arms (homosomal) or the result of fusion of arms and that interchromosomal changes of the translocation type are rare or non-existent. Since the most closely related species of *Drosophila* show numerous genic as well as structural differences, the full story of chromosomal evolution in the genus must be very complex.

In another chapter White tackles the old problem of the significance of chromosome number and form. He shows that in those cases where the evidence is not too fragmentary the picture is much like that in *Drosophila.* The lack of giant chromosomes such as those found in the salivary gland cells of the Diptera indicates that in that order only can we expect to obtain any really detailed knowledge of the interrelations of chromosome number and form.

The evolution of meiosis and the chromosome cycle are dealt with in a fascinating chapter devoted to deviations from the normal meiotic process. Most of these deviations are found in the meiosis of males and consist of simplification or suppression; meiosis in females is seldom anomalous. Although the general significance of anomalous meiotic mechanisms is considered by White to be far from clear, it is fairly evident that they all have the effect of reducing the recombination index. Hybridization and hybrid sterility are dealt with in a separate chapter which emphasizes meiotic disturbances.

An outstanding chapter is that on the evolution of sex-determining mechanisms, a review of a field in which White is a specialist. In general it can be stated that XO mechanisms have arisen from XY by inactivation and loss of the Y chromosome. Exceptional cases

of the origin of XY from XO forms by translocation between the X and an autosome are known in Orthoptera.

The general subject of the evolution of parthenogenesis and a review of the cytology of thelytoky occupy another chapter. In facultative parthenogenesis meiosis is of the usual type, but in obligatory parthenogenesis bivalents usually fail to form and the division that does occur is a mitosis. The latter type of parthenogenesis is therefore ameiotic. With the disappearance of meiosis and the sex-determining mechanism, the two principal barriers to polyploidy in bisexual organisms, the way is opened for the formation of polyploid species or races among forms with obligatory parthenogenesis. The more or less classical cases of this are presented and followed by a review of more recent work, notably that of Seiler on the races of psychid moths of the genus *Solenobia.* The chapter concludes with a treatment of cyclical parthenogenesis in the aphids and gall wasps.

In a final chapter White summarizes those generalizations which can be made from the data presented in the body of the book and points out difficulties which stand in the way of any complete generalizations (on the basis of the information available) concerning evolutionary patterns. While this discussion may seem tentative and incomplete to some, the point of view taken strikes the reviewer as extremely healthy. White's book is a highly significant contribution to cytology and evolutionary biology. The physical make-up is in the tradition of the Cambridge University Press. There are excellent author, organism, and subject indices as well as an extensive bibliography. D. F. POULSON.

Astronomy, A Textbook, Fourth Edition; by JOHN CHARLES DUNCAN. Pp. viii, 500; 318 figs. New York and London, 1946 (Harper & Brothers, $4.50).—In its first three editions this book has found wide acceptance as a text for an elementary descriptive college course in astronomy. The material in this new edition shows a considerable amount of rearrangement and revision, but the book has retained much of its previous character. It contains a new chapter on celestial navigation, a subject that may well become an established topic to be included in introductory courses in astronomy. Among the illustrations, very well done throughout the book, are some of the finest reproductions of celestial photographs that have ever appeared in a textbook.

DIRK BROUWER.

American Journal of Science

OCTOBER 1946

THE TACONIC SEQUENCE IN PENNSYLVANIA.

GEORGE W. STOSE

ABSTRACT. Ordovician shales in eastern Pennsylvania, generally mapped as Martinsburg, contain a series of rocks that differ in lithology, fauna, and age limits from those of typical Martinsburg shale. This series of rocks is described and compared with the Taconic sequence in eastern New York. Possible fault relations of these rocks with typical Martinsburg shale and underlying limestones in the area are described. The suggestion is made that this series of rocks may be a klippe of the Taconic sequence overthrust from the east and now resting on true Martinsburg shale and older limestones. Its possible relation to the rocks of the Martic overthrust block is discussed.

A WIDE belt of Ordovician shales, which forms the western part of the Great Valley of Pennsylvania, enters the State from New Jersey and extends southwestward across the State (Fig. 1) and passes into Maryland, West Virginia, and Virginia. These shales have been regarded as a formational unit and have been named Martinsburg shale from Martinsburg, W. Va., where they lie in the Massanutten syncline. The Ordovician shales in Pennsylvania are overlain by quartzose rocks of Upper Ordovician and Silurian age which form Blue Mountain, also called Kittatinny Mountain at Delaware River in northeastern Pennsylvania and North Mountain in the southern part of the State.

The typical Martinsburg shale ranges in age from middle Trenton at the base to Maysville at the top, and normally overlies limestones of Black River and lower Trenton age. The general sequence of associated formations southwest of the Susquehanna River is as follows:

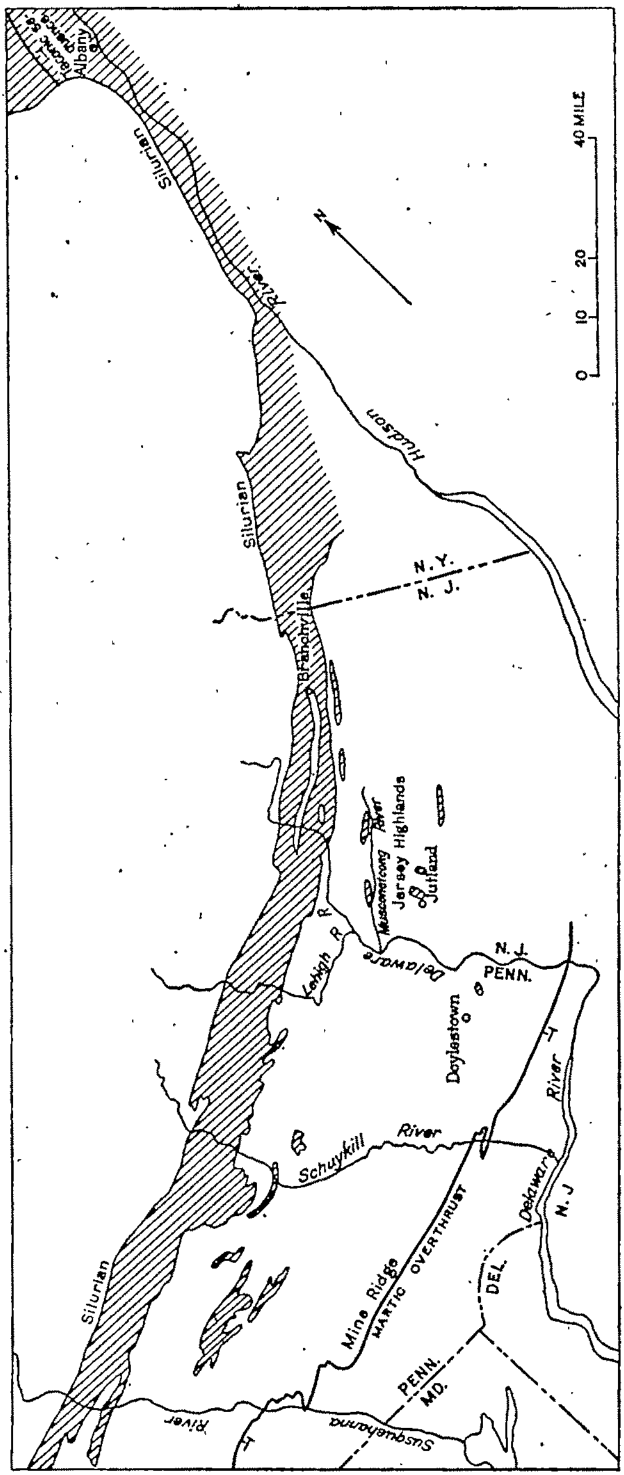

Fig. 1. Map showing distribution of Ordovician shale in eastern Pennsylvania, New Jersey, and southeastern New York. Shows main belt of shale and detached areas lying to the southeast by ruled pattern. Also shows Taconic sequence and bounding fault in eastern New York overlapped by Silurian rocks, and the Martic overthrust in Pennsylvania.

Sequence of Ordovician and Associated Formations Southwest of Susquehanna River.

Silurian	Tuscarora sandstone		*Feet*
Ordovician	Juniata formation	Red shale and sandstone.	400±
	Oswego or Bald Eagle sandstone.	Coarse gray sandstone and conglomerate.	150±
	Martinsburg shale.	Mainly dark-gray to black fissile shale; contains fossils of middle and upper Trenton and Eden age; upper part, soft greenish arkosic sandstone and sandy shale; contains fossils of Pulaski and Maysville age.	2000±
	Chambersburg limestone.	Thin-bedded to cobbly blue to dark-gray limestone; contains fossils of Black River and lower Trenton age.	600±
	Lowville and Stones River limestones.	Pure fine-grained, even-grained limestone (calcilutite); contains fossils of Chazy age.	700–1000±
	Beekmantown limestone.	Blue banded limestone and magnesian limestone.	2000–2300±
Cambrian	Conococheague limestone.	Siliceous banded blue limestone and thin sandstones.	1500±
	Elbrook limestone.	Shaly earthy-weathering limestone.	3000±

Northeastward from Susquehanna River, extending nearly to Lehigh River, the Ordovician shales have a markedly different lithology and stratigraphic relation. In contrast with the uniformly gray argillaceous shale and sandstones of typical Martinsburg this argillaceous sequence contains red and green shale, hard, green cherty shale or chert, thick-bedded quartzite, thick-bedded granular quartzose limestone with round glassy quartz grains, conglomerates containing pebbles of shale and limestone, thin-bedded blue limestone with interbedded shale, and limestone conglomerate. Throughout this area also the Chambersburg limestone or its equivalent, the Jacksonburg

limestone, is not everywhere present beneath the shale and is represented in places by variable thicknesses of cement rock which probably represents part of the Jacksonburg limestone. Where this limestone or the cement rock is absent, the shale rests on older limestones, ranging in age from Beekmantown (Lower Ordovician) to Elbrook (Middle Cambrian).

The shales and limestones in the area between Susquehanna and Lehigh Rivers contain fossils of probably Trenton age, and some shales contain graptolites of Normanskill and Deepkill (Beekmantown) age.[1] These graptolite faunas suggest the presence in this area of the Taconic sequence which, in eastern New York and Quebec, is an argillaceous, sedimentary series ranging in age from Lower Cambrian to Trenton. This series in New York was deposited far to the east of its present position and was thrust westward and now rests on carbonate rocks in part of the same age.

Kay[2] has suggested that the shales carrying Deepkill and Normanskill graptolites in Pennsylvania may occur as an outlier of the Martic overthrust to the southeast. Ashley[3] has recently suggested that these graptolite-bearing shales may represent the rocks in the Levis trough of New York and Quebec. The writer, having mapped the Martinsburg shale in southern Pennsylvania,[4] where it has the uniformly gray argillaceous character typical of that formation, later studied the shale in the vicinity of Jonestown in eastern Pennsylvania, and was so struck by the different lithology of those rocks that at first[5] he suggested the Triassic age of the red shale and arkosic sandstone of that area because of their close resemblance to the rocks in the main Triassic belt of Pennsylvania.

Willard,[6] who endeavored to work out the sequence and rela-

[1] Stose, George W.: 1930. Unconformity at the base of the Silurian in Southeastern Pennsylvania: Geol. Soc. Amer. Bull., 41, 638-641.

[2] Kay, G. M.: 1941. The Taconic allochthone and the Martic thrust: Science, 94, p. 73.

[3] Ashley, George H.: 1945. Possible extension of the Levis trough into Pennsylvania: Abstract, Geol. Soc. Amer. Bull. 56, p. 1145.

[4] Stose, George W.: 1909. Mercersburg-Chambersburg folio, U. S. Geol. Surv. Geol. Atlas No. 170.

[5] Stose, George W., and Jonas, Anna I.: 1925. Triassic sedimentary rocks and basaltic flow northwest of Lebanon, Pa.: Abstract, Geol. Soc. Amer. Bull., 36, 160-161.

[6] Willard, Bradford: 1943. Ordovician clastic sedimentary rocks in Pennsylvania: Geol. Soc. Am. Bull., 54, 1067-1122.

tions of the Ordovician shales east of Susquehanna River, stated that "much of the lower Martinsburg from Susquehanna River into New Jersey appears, from its graptolites, to be of Normanskill age, except the Deepkill forms, yet the underlying limestones..are generally younger....It might be supposed that the Deepkill shale was faulted up among the younger beds, but no structural evidence was seen....Peculiar circumstances ....seem to have permitted a few Deepkill graptolites to survive into post-Trenton time." Miller,[7] who described the limestones in and beneath these Ordovician shales, regards many of the limestones to be (p. 100) "lenses of limestone deposited at different times subsequent to the deposition of the oldest Martinsburg shale." He states also that the thick massive siliceous limestone, 100 feet thick, is (p. 103) "of a lithology not common to the Martinsburg limestones in the western region."

All geologists who have studied the Ordovician shales in eastern Pennsylvania have noted the marked difference in lithology, stratigraphic sequence, and fossil content of the part of the main shale belt between Susquehanna River and Lehigh River. East of the Lehigh the Ordovician shales again are uniformly of argillaceous character like those west of the Susquehanna, and the name Martinsburg is appropriately applied to them. The question arises, could such a marked change in lithologic and faunal characters be gradational, and could these types of rocks which are unusual in the Martinsburg have been deposited in situ? On the banks of the Susquehanna, where bright-red and green shales and associated thin-bedded limestones first appear, the change is abrupt from the uniformly gray argillaceous shale of the Martinsburg west of the river. The limestones exposed in anticlines on the banks of the Susquehanna were formerly regarded by the writer as cement rock of the type present in the Jacksonburg, which underlies the shale in eastern Pennsylvania. The few fossils found in these limestones, however, indicate Chazy age, whereas the cement rock of the Jacksonburg is of Black River and lower Trenton age. Conglomerates containing pebbles of limestone and shale in a coarse arkose matrix, which occur higher in the section east of

[7] Miller, Ralph Le Roy: 1937. Martinsburg limestones in Eastern Pennsylvania; and Stratigraphy of the Jacksonburg limestone: Geol. Soc. Amer. Bull., 48, pp. 93-112, and pp. 1687-1718.

Susquehanna River, have a fauna of lower Trenton age, about equivalent to that of the Jacksonburg. These beds of Trenton age are overlain by Silurian rocks in Little Mountain north of Lebanon, and the sandy beds which contain a Pulaski fauna, present in the upper part of the Martinsburg northeast of Hamburg, are not present in the section at Little Mountain. Normanskill graptolites, which have been found at several places in the area between Susquehanna and Lehigh Rivers, appear to lie above the horizon of the Chambersburg and Jacksonburg limestones. Deepkill graptolites of Beekmantown age, which have been found in the northern part of the shale area north of Harrisburg, lie 8 miles north of exposures of Beekmantown limestone, hence it is improbable that the shales containing these graptolites are a gradational facies of the Beekmantown limestone. There is no doubt about the large graptolite fauna from the northern part of the shale area on Susquehanna River being identical with that at Deepkill, N. Y. This fauna is known only from the Taconic sequence in eastern New York and western New England, and is of Beekmantown age. The Deepkill shale and associated argillaceous rocks of the Taconic sequence in New York were deposited far to the east and were thrust westward, and now overlie Beekmantown limestone and other rocks of the western carbonate sequence. It seems reasonable to conclude that the shale which contains the Deepkill fauna on Susquehanna River could not have been deposited where it now is found, but, as in the case of similar shales in eastern New York, was deposited far to the southeast and, with the associated argillaceous beds, was thrust northwestward over the Beekmantown limestone and higher beds on which they now lie.

The writer therefore suggests that the stratigraphic anomalies and the lithologic variability of the Ordovician shale in the main shale belt east of Susquehanna River is due to the superposition of two distinct sequences of rocks of approximately the same age; that the group of rocks that differs lithologically from typical Martinsburg shale, some beds of which contain Normanskill and Deepkill graptolite faunas, are part of an eastern argillaceous sequence of Beekmantown to Trenton age, similar to that of the Taconic sequence, and that they have been thrust westward and now rest on true Martinsburg shale and in places on limestone older than the Martins-

burg. The overridden typical Martinsburg comprises an even-grained gray to black argillaceous shale, some beds of which, in the eastern part of the State, have been metamorphosed to commercial slate, and overlying sandy shale and sandstone which contain fossils of Pulaski age. Northeast of Hamburg, Pa., where these sandy beds are enclosed in a syncline they form Shochary Ridge in Berks and Lehigh Counties. The overthrust shale sequence regarded as "Taconic" in places contains gray to black argillaceous shales similar to those in the typical Martinsburg, and when these similar shales of both sequences are in contact, it is difficult to distinguish the overthrust from the overridden rocks. The writer believes that a presentation of the present known facts and a suggested solution of the relations of the rocks will prove of value to future study, which is much needed to establish the exact sequence of the rocks which resemble the Taconic sequence, and to prove their fault relations to the underlying rocks.

Sequence of Beds in the "Taconic Sequence" of Pennsylvania.

The order of beds in the proposed "Taconic thrust block" is difficult to determine because of close folding, the presence of overturned folds and cleavage which in places has obliterated the bedding, and lack of knowledge of the top or bottom of the series. Two horizons of limestones seem to be present: one above and the other below a medial series of red, green, and gray shales. On the basis of the present knowledge of these rocks the writer has recognized five mappable units in the "Taconic sequence" of Pennsylvania which deserve to be given formation names. The beds in these formations are variable in character and thickness, and the units, except the conspicuous red and green shales, are difficult to trace from place to place. Therefore, before they are given names, more detailed study is necessary to establish their unity, determine their thicknesses, and prove their relations to one another and to the adjacent formations. More fossils also must be collected to establish their correlation with formations in the Taconic sequence of New York. In the following table the formational units suggested by the writer are not given names but are numbered, and are listed in order from the youngest downward.

"Taconic Sequence" in Eastern Pennsylvania.

5. Thin-bedded blue limestone with shale partings, limestone conglomerate, and thick-bedded limestone with glassy quartz grains; contains crinoid segments and brachiopods of probably Trenton age.

4. Thick-bedded massive, coarse calcareous quartzite or highly quartzose limestone with glassy quartz grains.

3. Coarse arkosic sandstone, the upper part containing arkosic conglomerate with pebbles of slate, chert, and limestone, called chip conglomerate by Willard; contains lower Trenton fossils.

2. Gray to black shale, containing graptolites of Normanskill and Deepkill age, underlain by red and green shales.

1. Coarse, thick-bedded limestone with glassy quartz grains and calcareous quartzite, underlain by thin-bedded limestone with shale partings; contains crinoid segments, *Leperditia,* and an orthoid shell, said to suggest middle Chazy age.

The units here recognized will be next described in more detail, beginning with the oldest.

FORMATION 1.—The limestones which crop out on the banks of Susquehanna River and in stream valleys east of the river, north of Harrisburg, seem to be exposed in anticlines and are regarded as the oldest rocks in the "Taconic series." They directly underlie red, green, and buff shales.[8] One of the best exposed sections of these limestones is one mile south of Enola, three miles northwest of Harrisburg, where the following section is shown:

Section of Limestones 1 Mile South of Enola.	*Feet*
Gray and red shale.	
Gray shale with scattered beds of thin limestone.	50±
Thin platy to ribbon-banded light- to dark-gray, fine-grained to granular limestone with interbedded dark shale.	60±
Thicker-bedded limestone, in part conglomerate of light-colored limestone in dark matrix and containing many round glassy quartz grains. The conglomerate beds contain an orthoid shell, *Leperditia,* and crinoid segments, which suggest middle Chazy age.	25±
Well-bedded blue to gray magnesian limestone (may be top of underlying limestone).	10±

These limestones are exposed again at several places northwest of Annville on Quitapahilla and Swatara Creeks and their

[8] Stose, George W.: Geol. Soc. Amer. Bull., 41, idem, p. 637.

tributaries. On Quitapahilla Creek, 2 miles northwest of Annville, an anticline of limestone is exposed clearly underlying red, green, and gray shales. The section is as follows:

Limestone Exposed on Quitapahilla Creek, Pa.

	Feet
Red, green, and gray shales.	
Siliceous dolomite.	2±
Thin-bedded, dark, quartzose limestone and interbedded shale; some of the limestone contains glassy quartz grains.	80±
Massive quartzose limestone or calcareous quartzite.	6
Dark limestone and interbedded shale.	20±

At Harpers Tavern on Swatara Creek the following section of these lower limestones is exposed in an anticline:

Section at Harpers Tavern.

	Feet
Black, platy, argillaceous limestone, flecked with mica, and interbedded shale.	20±
Thin-bedded to platy, dark, fine-grained, siliceous to argillaceous limestone with thin shale partings in upper part.	100±
Thin-bedded, lamillar, crossbedded sandy limestone with trail markings on bedding surfaces, and irregular, dark, argillaceous partings.	6
Thick, quartzose, blue limestone.	20

Farther east at Jonestown, northwest of Lebanon, thick quartzite, a basalt flow, and limestone beneath red, green, and black shales are believed to represent the limestones of formation 1, but they may be still lower beds of the "Taconic sequence" as explained later in this paper. The section of these beds is as follows:

Section at Jonestown, Pa.

	Feet
Red, green, and gray shales.	
Massive quartzite (may have been quartzose limestone altered by igneous action).	60±
Basalt lava flow; contains fragments of indurated limestone.	300±
Thick-bedded dark-blue to gray limestone (resembles underlying Beekmantown limestone[9]).	

Limestones exposed in the railroad cut just west of Lebanon seem to be the lower limestones of the "Taconic sequence," although they are not directly associated with red shale. The section of these limestones is as follows:

[9] Stose, George W., and Jonas, Anna I.: 1927. Ordovician shale and associated lava in southeastern Pennsylvania: Geol. Soc. Amer. Bull., 18, 526–532.

Section in Railroad Cut West of Lebanon.

	Feet
Gray shale.	
Platy limestone (1″ beds) and irregular bedded limestone (2-4″ beds) with shale partings.	45
Massive limestone with round, glassy quartz grains.	
Shale and thin-bedded limestone (may be the overlying beds repeated by folding).	
Thick-bedded, dark, granular, siliceous limestone (2-8″ beds) with shale partings.	80±

FORMATION 2.—The limestones exposed on both banks of Susquehanna River and in valleys northeastward to Quitapahilla and Swatara Creeks are overlain by red and green shales. Similar red and green shales have been observed in bands which extend eastward nearly to Lehigh River. The red and green shales are overlain by gray to buff-weathering shale, in which are beds of hard dense green cherty shale or chert. Some of these gray shales contain graptolites of Normanskill age, and at one place on Susquehanna River they contain a graptolite fauna of Deepkill (Beekmantown) age.[10] The writer also collected graptolites, regarded by Ulrich as probably Normanskill, from shaly arkosic sandstone at Steelton, Dauphin County, 4 miles southeast of Harrisburg. Willard[11] reports 3 species of graptolites of probably Normanskill age from the vicinity of Steelton, one species from a nearby place one and one-half miles southeast of Oberlin in the same County, and 6 species of undoubted Normanskill age from two miles southeast of Manada Gap, Dauphin County.

FORMATION 3.—The gray shales containing graptolites in places are overlain by thick-bedded, coarse, arkose, in the upper part of which are fine conglomerates. These conglomerates are poorly sorted and contain angular fragments of limestone, shale, and chert in an arkosic matrix. Some of these conglomerates are so distinctive in appearance that the writer has used them as a key horizon in determining the sequence of beds. In this paper they will be referred to as limestone-shale-pebble conglomerate. Willard[12] called them chip conglomerates, and states that he could trace them for long distances along the strike.

[10] Stose, George W.: Geol. Soc. Amer. Bull., 41, idem, pp. 638-641.
[11] Willard, Bradford: idem, p. 1099.
[12] Willard, Bradford: idem, p. 1078.

The best exposures of these limestone-slate-pebble conglomerates are found north of Lebanon on the slopes of Little Mountain and on other high hills in the vicinity. These high hills are an outlying, detached ridge of Blue Mountain and are capped by hard, white, Silurian quartzite like that on Blue Mountain.

The Silurian quartzite of Little Mountain is unconformable to the underlying limestone-shale-pebble conglomerate because higher beds which lie above the conglomerate elsewhere are not present at Little Mountain. Fossils have been collected by the writer at three places in this vicinity: On a high hill one mile northwest of Bethel; on a lower hill in the same strike five miles west of Bethel; and on the east end of Little Mountain three miles northwest of Bethel. These fossils, as identified by Ulrich, comprise *Pachydictya* aff. *acuta*, *Rhinidictya* sp., another undetermined bifoliate bryozoan, and an orthoid shell. According to Ulrich, these forms suggest lower Trenton age.

Westward from Little Mountain the limestone-shale-pebble conglomerate was observed at only one place, at Progress, three miles northeast of Harrisburg. Eastward from Little Mountain where the upper beds of the series are more widely exposed, the limestone-shale-pebble conglomerate is more plentiful. In that area the writer found the conglomerate on Schuylkill River north and south of Hamburg, and at Kempton and Wassnersville near Maiden Creek, and Willard has traced it eastward as far as Lowhill, Lehigh County.

FORMATION 4.—The coarse arkose containing the limestone-shale-pebble conglomerate just described is overlain by thick-bedded highly quartzose limestone with glassy quartz grains, or calcareous quartzite, several hundred feet thick. On the upland the quartzose limestone generally weathers to porous sandstone. On the north branch of Sacony Creek, three miles northwest of Kutztown, the limestone-shale-pebble conglomerate dips south and is overlain by shaly beds followed by thick-bedded quartzose limestone with glassy quartz grains. At Sacony Creek the quartzose limestone lies nearly horizontal, and south-

ward on the creek the beds dip north. The thick-bedded quartzose limestone evidently is enclosed in a syncline and overlies the limestone-shale-pebble conglomerate. North of Kutztown and westward there is an east-west belt of the thick-bedded quartzose limestone 200 feet thick in which are located Crystal and Onyx Caves described by Miller.[13] It is these limestones that Miller states are of a type not commonly found in the typical Martinsburg west of the Susquehanna.

FORMATION 5.—At Leesport and northward on Schuylkill River the thick-bedded calcareous quartzite is overlain by, and possibly interbedded with, thin-bedded to platy siliceous limestone having shale partings. The platy limestone resembles the cement rock of the Jacksonburg and was formerly called the Leesport limestone.[14] The sequence of the limestone at and north of Leesport is confused, but partial sections are as follows:

Section of a Syncline 1½ Miles North of West Leesport.

	Feet
Thin-bedded shaly sandy limestone.	8
Thick homogeneous calcareous blue quartzite.	10
Thinner bedded calcareous sandstone.	5

Section of Beds Dipping 75° S. Near West Leesport.

Thick-bedded calcareous quartzite.	10±
Concealed.	30±
Thick-bedded bluish calcareous quartzite.	10
Thin-bedded limestone (1-inch beds) with shale partings.	70
Thick-bedded calcareous quartzite with limestone conglomerate at top.	20
Shale.	

In a previous publication[15] this section was inverted on the assumption that the beds were overturned. At West Leesport, south of the section given just above, 70 feet of thin-bedded limestone and 35 feet of massive calcareous sandstone are exposed, as is illustrated by Miller,[16] but the order of sequence is not clear.

[13] Miller, Ralph L.: 1941. The origin of Crystal and Onyx Caves, Pennsylvania: Pa. Acad. Sci. Proc., 15, 68–73.

[14] Stose, George W., and Jonas, Anna I.: idem, pp. 510–511.

[15] Stose, George W., and Jonas, Anna I.: idem, p. 511.

[16] Miller, Ralph: Stratigraphy of the Jacksonburg limestone, loc. cit., p. 1711.

A comparison of the proposed new formational units in eastern Pennsylvania with those recognized in the Taconic sequence of eastern New York shows similarities other than the presence in both of them of Normanskill and Deepkill graptolite

Tentative Correlation Chart, Taconic Sequence.

Southeastern Pennsylvania.	*Eastern New York*	
Thin-bedded limestone and interbedded shale; contains fossils of probably Trenton age. Thick-bedded calcareous quartzite or quartzose limestone, coarse arkose and limestone-shale-pebble conglomerate; contains lower Trenton fossils.	Snake Hill shale; dark shale and conglomerate. Rysedorph conglomerate; limestone conglomerate, the pebbles of which contain fossils ranging from Lower Cambrian to Trenton.	Ordovician
Dark shale with green chert beds; contains Normanskill graptolites.	Normanskill shale; black shale, graywacke, red and green shale, and chert; contains graptolites of Normanskill age.	
Soft buff-weathering shale; contains Deepkill graptolites. Red and green shale and some gray shales.	Deepkill shale; contains graptolites of Beekmantown age.	
Thin-bedded limestone, quartzose limestone, limestone conglomerate; contains *Leperditia* and other fossils of probably lower Ordovician age.	Bald Mountain limestone; contains *Leperditia* and other fossils of Beekmantown age. (Position in stratigraphic column not determined). Schaghticoke shale; black to green shale and interbedded thin gray limestone.	
Red shale, thick hard quartzite, and basalt flow exposed south of Jonestown. May be older than the above limestone and may be equivalent to lower Cambrian formations.	Schodack shale and limestone. Troy shale; green to red and purple shale. Diamond Rock quartzite. Bomoseen grit. Nassau beds; red and green shale and quartzite.	Lower Cambrian

faunas. The limestone-shale-pebble conglomerate, containing a lower Trenton fauna, resembles and may be the equivalent of the Rysedorph conglomerate. The graptolite-bearing shales and associated red and green shale are probably equivalent to

the Normanskill and Deepkill shales. The lower limestones and limestone conglomerate, which contain *Leperditia* and other lower Ordovician fossils, may be the equivalent of the Bald Mountain limestone which contains *Leperditia* and other fossils of Beekmantown age. A tentative correlation based on similarity of lithologic character and on meager faunal evidence is presented in the preceding table.

There is no known paleontologic evidence of the occurrence in Pennsylvania of the Lower Cambrian formations which are present in the Taconic sequence of western New England. It is possible that the red and green shales, thick massive hard quartzite, basalt flow and associated diabase sills, and thick-bedded limestone which occur south of Jonestown may represent these Lower Cambrian rocks. These rocks south of Jonestown are in a fault block bounded on the east and west by cross faults,[17] and may be an uplifted block in which Lower Cambrian rocks are exposed. Basaltic and diabasic rocks occur in the Taconic sequence of New York associated with the Normanskill shale at Starks Knob,[18] near Schuylerville, N. Y.; in the Berkshire schist and Rensselaer graywacke of probable Lower Cambrian age;[19] and in the older rocks of the Magog syncline[20] in Quebec.

EVIDENCE OF OVERTHRUSTING.

Main Shale Belt.

On the map of eastern Pennsylvania in Fig. 2 the rocks that are tentatively assigned by the writer to the "Taconic Sequence" are separated from those that are regarded as typical Martinsburg. The line which separates these two groups of rocks is shown as a thrust fault, and the fault block of the "Taconic sequence" is called the Hamburg klippe. It extends from the west side of the Susquehanna River northeastward

[17] Stose, George W., and Jonas, Anna I.: idem, Fig. 7, p. 528.

[18] Cushing, H. P., and Ruedemann, R.: 1914. Geology of Saratoga Springs and vicinity: N. Y. State Mus. Bull. 169, 115-185.

[19] Dale, T. Nelson: 1892. The Rensselaer grit plateau in New York: U. S. Geol. Surv. 13th Ann. Rept., pt. 2, p. 327.

Prindle, Louis M., and Knopf, Eleanora Bliss: 1932. Geology of the Taconic quadrangle: AMER. JOUR. SCI., (5), 24, 282-284.

[20] Dresser, John A., and Denis, T. C.: 1944. Geology of Quebec: Quebec Dept. Mines, Rept. 20, 2, 372-386.

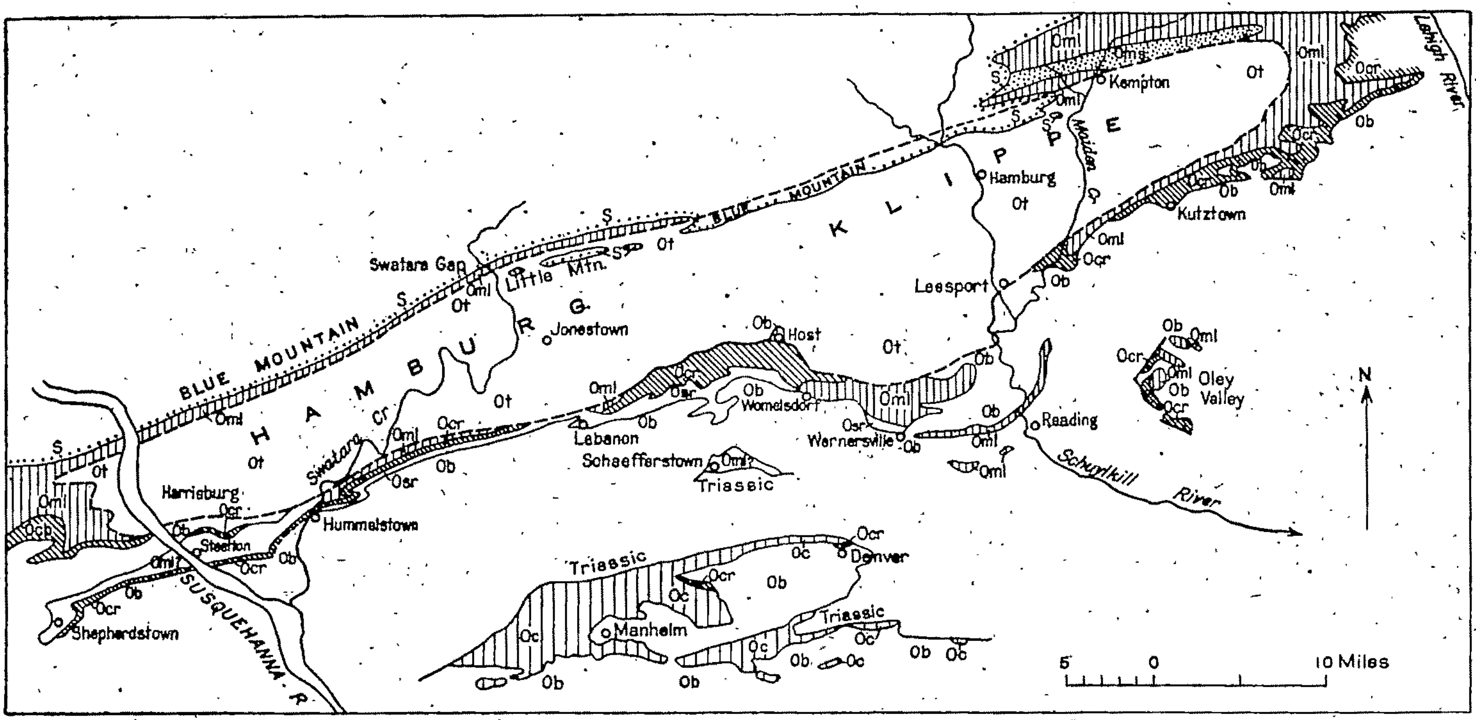

Fig. 2. Map showing the suggested "Hamburg klippe" of the "Taconic sequence" in eastern Pennsylvania and its relations to overridden rocks. Ot, Rocks assigned to the "Taconic sequence." S, Silurian rocks; Oms, Shochary sandstone, upper part of Martinsburg shale; Oml, lower part of Martinsburg shale; Oc, Cocalico shale; Ocb, Chambersburg limestone; Ocr, cement rock, Jacksonburg limestone; Osr, Stones River limestone; Ob, Beekmantown limestone.

nearly to Lehigh River. In areas where data are lacking and there is no known evidence of faulting, the location of the fault is drawn somewhat arbitrarily. Exposures of shale along the south border of the postulated klippe seldom show the dip of the beds, and there clear evidence of faulting is generally lacking. Search for such evidence is much needed to establish fault relations and determine the location of the fault. The writer realizes that, because of incomplete knowledge, the mapping indicated in Fig. 2 is subject to modification as the result of more detailed field work.

The most convincing evidence which the writer has that the "Taconic sequence" is thrust over typical Martinsburg shale in eastern Pennsylvania is in the vicinity of Kempton. North of Kempton the sandy beds of Shochary Ridge and the black shale and commercial slate north of the ridge are undoubtedly Martinsburg. The black commercial slate makes a nearly straight northeast-trending band (Fig. 3) and is overlain by south-dipping calcareous shale which carries crinoid segments and brachiopods of middle Eden age. These beds are overlain by fossiliferous sandy beds which contain a fauna of Pulaski age.[21] The sandy beds form Shochary Ridge and were named Shochary sandstone by Willard.[22] The Shochary sandstone is the upper member of the typical Martinsburg shale in this area, and is enclosed in a tight asymmetric syncline, the south limb of which is vertical (Fig. 3). Fossils of Pulaski age were collected by Willard (p. 1096) on Shochary Ridge eastward as far as Jordan Creek, south of Pleasant Corners. At Kempton and westward, soft argillaceous shales, which are the lower part of the Martinsburg and contain an Eden fauna, are present south of the syncline. East of Kempton these soft shales wedge out and are evidently cut out by the fault. South of Kempton red shales, limestone-pebble conglomerate, and hard arkosic sandstone of the "Taconic sequence" are closely folded, as is shown by the intricate pattern of their outcrop in Fig. 3, contrasting strongly with the straight-line pattern of the typical Martinsburg north of the fault. At the contact of the two series, the shales are much crumpled. It seems clear that, in the vicinity of Kempton, closely folded rocks of the "Taconic sequence" are thrust northward over less-disturbed Martins-

[21] Stose, George W.: idem, pp. 648–649.
[22] Willard, Bradford: idem, p. 1097.

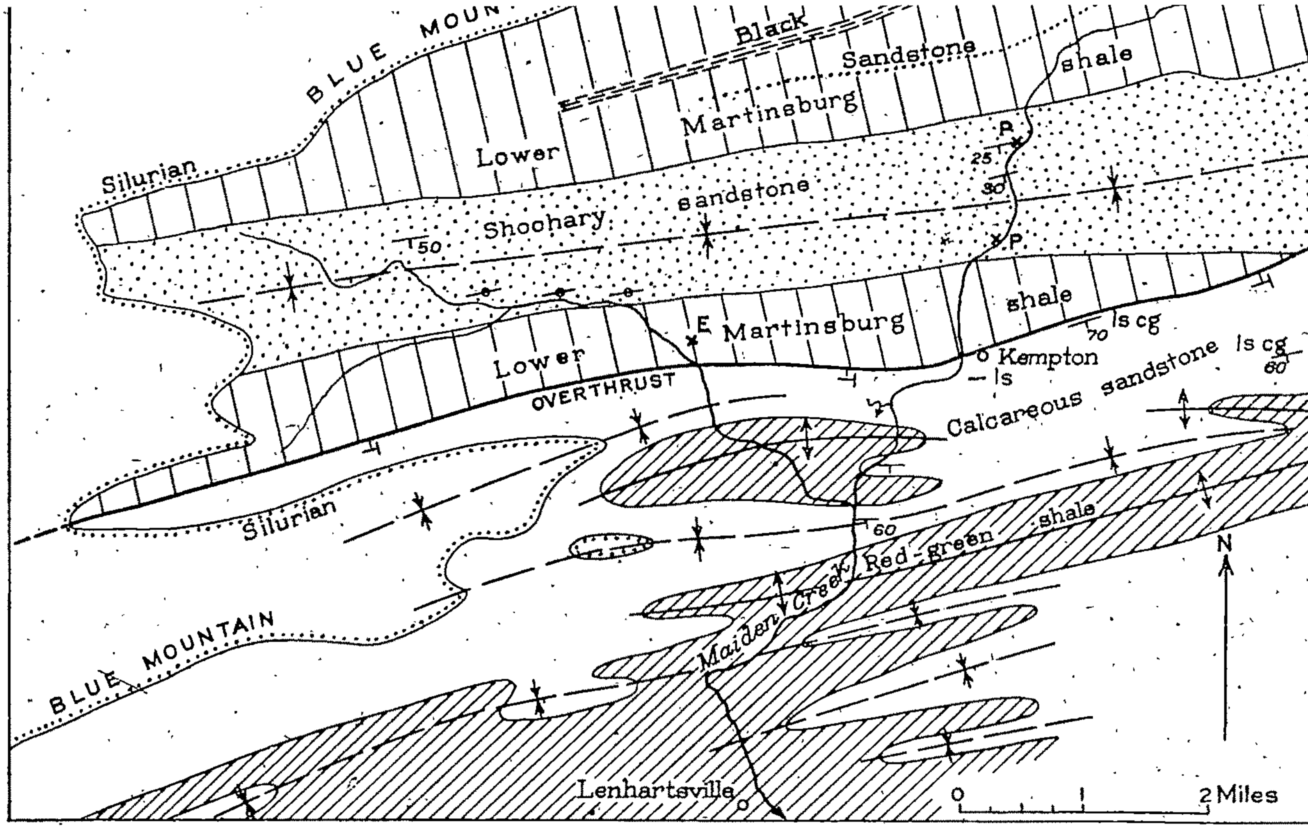

Fig. 3. Map showing relations near Kempton, Pa. North of Kempton, an open syncline encloses Shochary sandstone, the upper part of the Martinsburg shale. South of Kempton, calcareous sandstone and limestone conglomerate and red and green shale of the "Taconic sequence" are closely folded. The fault between these two sequences passes through Kempton and at Blue Mountain is overlapped by Silurian rocks.

burg shale and that the "Taconic sequence" here overrode the soft lower beds of the Martinsburg and eastward abut against a syncline of Shochary sandstone of Pulaski age, the upper part of the Martinsburg.

Evidence of faulting on the borders of the Hamburg klippe will be next described. The south edge of the klippe will be described first, beginning at Susquehanna River and continuing eastward.

East of Susquehanna River, just south of Harrisburg and extending eastward nearly to Hummelstown, the shale hills rise abruptly out of the limestone lowland in an almost straight line. No dips were observed in the shale near the contact, but at one place a hard sandstone not characteristic of the base of the Martinsburg crops out close to nearly vertical limestone. The limestone south of the shale is chiefly Beekmantown and everywhere dips steeply south. The Stones River and overlying Chambersburg limestones, which are present beneath the shale west of the Susquehanna, are absent east of the river. In the railroad cut west of the river there is evidence of faulting between the limestone and shale. The Chambersburg limestone at the contact is crushed and slickensided and its full thickness is not present. The contact of the shale and limestone east of the river is believed, therefore, to be a fault, although definite proof is lacking.

Near Hummelstown a long narrow area of shale extends southwestward from the main shale belt and diagonally crosses the limestone valley. This shale area passes through Steelton and ends at a point two and one-half miles southwest of Shepherdstown, where it is cut off on the south side by the Triassic border fault. Near Shepherdstown the west edge of the shale area transgresses folds in the Beekmantown and Conococheague limestones. At its southwest end the shale overlaps folds in the Elbrook limestone.[28] The shale near its contact with the limestone is crushed and veined with quartz, and the quartz contains pyrite. Just west of Hummelstown in this belt, purple and green shales and hard sandstone, not characteristic of typical Martinsburg shale, are exposed at the north margin of the shale. Graptolites of Normanskill age have been collected from gray shale in this belt at several places near Steel-

[28] Geologic map of York County, Pennsylvania: Pa. Geol. Surv. Bull. C 67, Pl. 1, 1939.

ton and Shepherdstown. The presence of purple and green shale and hard sandstone and the graptolite fauna suggest the "Taconic sequence." The crushed character of the shale, the presence of quartz veins, and the stratigraphic and structural discordance of the shale to underlying formations suggest faulting. This long, narrow, shale area, therefore, may be part of the Hamburg klippe resting in thrust relation on older limestones. However, cement rock of the Jacksonburg type underlies (overturned so that it overlies) the shale along the whole length of the south margin, and was observed also at two places on its north border. The cement rock contains bryozoa, brachiopods, cystid plates, and crinoid segments of probably lower Trenton age, similar to fossils present in the Jacksonburg. It would be remarkable if the shale were thrust to its present position and came to rest on the cement rock in apparent stratigraphic position. Furthermore, the colored shale west of Hummelstown is purple and not bright red as is that in the "Taconic sequence." The shale in this area, therefore, may be an overturned syncline of Martinsburg shale, bordered by underlying cement rock of the Jacksonburg limestone, which has been much crushed and veined by intense folding. This belt of shale is continuous northeastward with soft gray shale and thin cement rock in minor synclines on the southeast border of the main belt east of Hummelstown, which are classed as Martinsburg. Further field study is necessary positively to determine whether the diagonal shale belt extending to Shepherdstown is a part of the thrust block of the "Taconic sequence" or is Martinsburg shale.

East of Hummelstown, along the south border of the shale belt, small folds enclose soft, buff shale, which is believed to be Martinsburg, underlain by thin cement rock of the Jacksonburg which rests in normal stratigraphic position on the Stones River limestone. These rocks are believed to be part of the overridden block, and the fault bounding the Hamburg klippe apparently lies to the northwest within the shale. If the Shepherdstown-Steelton shale area is Martinsburg, the fault may be continuous with the postulated fault at the shale border east of Harrisburg (Fig. 2).

Eastward, near Annville, red shale is present close to the south border of the shale, and the shale near the contact is injected by many small quartz veins. Several large springs

emerge along this contact, one of which, just north of Annville, is the source of that city's water supply. The Stones River limestone, which is extensively quarried west of Annville, dips 45° S., overturned, and in places is overlain by a narrow zone of cement rock. These limestones are part of the overridden block, and the fault apparently lies at the south edge of the shale.

At Lebanon also red shale is present at the south edge of the shale belt and the fault marks the contact with the limestone of the lowland. Thin-bedded limestone, exposed in the cut of the Tremont Branch of the Philadelphia and Reading Railroad just west of the town, is regarded as part of the overthrust "Taconic sequence." Three miles northeast of Lebanon and extending eastward to Womelsdorf, a wide belt of cement rock of the Jacksonburg type overlies the Stones River limestone in normal relation, and just east of Lebanon small areas of gray shale are enclosed in synclines in the cement rock. The cement rock and enclosed Martinsburg shale are evidently part of the overridden block and the south edge of the Hamburg klippe apparently lies north of the cement rock at the edge of the main shale area. At Host, northwest of Womelsdorf, there is clear evidence of faulting along the south border of the shale. Massive well-bedded dolomite crops out at Host between the shale and the cement rock. The dolomite is believed to be Beekmantown limestone exposed in an anticline in the cement rock of the overridden block. In the reëntrant in the shale front at Host, the dolomite strikes northwest and passes under the shale. The shale is contorted, crushed, stained red with iron, and is injected by vein quartz. The relations here indicate a thrust fault which dips north into the reëntrant. The hills of shale and sandstone on either side of Host are unusually high and rise sharply above the limestone lowland. Similar abruptly rising, high shale hills continue southeastward to and beyond Tulpehocken Creek. West of the creek the presence of abundant vein quartz and calcite and iron-stained shale bear evidence of a fault at the south border. East of Tulpehocken Creek the fault continues eastward between the shale on the north and cement rock and massive limestone, probably Beekmantown exposed in an anticline in the overridden block, to the south. The fault apparently continues eastward in the shale to a deep reëntrant in the shale front northwest of Reading,

where Beekmantown limestone in an anticline in the overridden block forms the reëntrant. South of this part of the fault, the wide belt of gray shale, which locally overlies cement rock west of Wernersville, is regarded as Martinsburg.

North of the reëntrant in the shale front, northwest of Reading, the shale contains thick conglomerate beds and makes precipitous bluffs that rise above the limestone lowland. The conglomerate is evidently part of the "Taconic sequence," and the abrupt hills at the contact with the limestone are believed to mark the edge of the overthrust block. West of Leesport, on Schuylkill River, where limestones believed to be the upper part of the "Taconic sequence" are present at the south edge of the shale belt, the fault lies at the contact with the Beekmantown limestone in the lowland. The rocks of the "Taconic sequence" exposed in the railroad cut at West Leesport are closely folded, sheared, and faulted, as previously stated under the description of the limestones at Leesport; but the contact of these rocks with the overridden Beekmantown limestone is not exposed.

Northwest of Kutztown a narrow belt of soft shale, which overlies the cement rock exposed at Kutztown, is regarded as Martinsburg. The fault apparently lies between this shale and the calcareous sandstone of the upper part of the "Taconic sequence" to the northwest. Northeastward the fault has been arbitrarily drawn between thick calcareous sandstone and red shale of the "Taconic sequence" on the west and soft shales and commercial slates, regarded as Martinsburg, on the east. The red shales of the "Taconic sequence," exposed in an anticline, end east of Werleys Corner.[24] The limestone-shale-pebble conglomerate of formation 3 of the "Taconic series" has been traced eastward to Lowhill. At the edge of the shale area east of the arbitrarily drawn fault, soft gray shale overlies unconformably the Beekmantown limestone and cement rock of the Jacksonburg. Here the irregular occurrence of cement rock suggests possible faulting, but the relations near the contact seem to be stratigraphic, and the shale is believed to be Martinsburg resting on the underlying rocks by depositional overlap.

The north edge of the "Hamburg klippe" will next be

[24] Behre, Charles H., Jr.: 1933. Slate in Pennsylvania: Pa. Topog. and Geol. Surv. Bull. M16, Pl. 25.

described, beginning at the east. The Martinsburg shale northeast of Kempton, comprising black commercial slate and soft shale at the base, calcareous slate with a middle Eden fauna in the middle, and at the top sandy beds of Shochary Ridge containing a Pulaski fauna, has already been described. The relation of the rocks of the "Taconic sequence" south of Kempton to the typical Martinsburg shale to the north, clearly suggests that the "Taconic sequence" has been thrust over the Martinsburg. (Fig. 8.) The fault at Kempton has been traced westward to Blue Mountain where it passes under the Silurian rocks north of the Pinnacle. Because the thrust fault is overlapped by the Silurian rocks it is pre-Silurian or Taconic in age.

Westward as far as Little Mountain, in the area north of Lebanon, all the shale south of Blue Mountain is of the "Taconic type," and the overthrust is buried by the Silurian rocks of the mountain. Little Mountain, an outlier of Blue Mountain, is also capped by Silurian sandstone which, as previously stated, overlies arkosic sandstone with fossiliferous limestone-shale-pebble conglomerate, the upper part of the "Taconic sequence." At Swatara Gap, just west of Little Mountain, black shales with an abundant middle Eden fauna[25] directly underlie the Silurian sandstone. The fauna of these fossiliferous beds is the same as that which occurs elsewhere in the lower part of the typical Martinsburg, and they are undoubtedly part of the overridden block. The fault, therefore, emerges from beneath the Silurian rocks east of Swatara Gap, probably in the valley north of Little Mountain, and passes south of the shale with the Eden fauna. To the westward a similar middle Eden fauna was collected by Willard[26] at Indian Gap, 5 miles southwest of Swatara Gap. At the Susquehanna Gap, the same fauna was collected by the writer[27] from soft gray shales 200 feet below the base of the Juniata sandstone of Blue Mountain. About 1,000 feet south of the shales with the Eden fauna, gray shales of the "Taconic sequence" yielded graptolite faunas of Normanskill and Deepkill age. The overthrust, therefore, must lie in the shale between these two outcrops. It is probable that a narrow belt

[25] Stose, George W.: idem, pp. 643-644.
[26] Willard, Bradford: idem, p. 1095.
[27] Stose, George W.: idem, p. 640.

of lower Martinsburg shale borders the foot of Blue Mountain from Swatara Gap to Susquehanna Gap and lies north of the "Hamburg klippe" composed of red shales and other characteristic beds of the "Taconic sequence."

Red shales are present on the west bank of Susquehanna River, but they are not known to extend farther west. The "Hamburg klippe" is therefore arbitrarily ended a short distance west of the river.

Martinsburg Shale East of Lehigh River.

The Ordovician shale at Lehigh River is of Martinsburg type and comprises 2 zones of roofing slate separated by a medial zone of sandy beds. Fossils of Pulaski age, similar to those in the sandstones of Shochary Ridge, were collected by Willard (p. 1097) from these medial sandy beds, and they undoubtedly represent the upper member of the Martinsburg. They are interpreted by the writer as occurring in a syncline, and the two zones of roofing slate are the lower member of the Martinsburg on either limb of the syncline. The Martinsburg shale is underlain on its south side by the Jacksonburg limestone in normal stratigraphic sequence. Eastward from Lehigh River the two members of the Martinsburg shale persist to Delaware River and the shale is underlain by Jacksonburg limestone.[28]

A broad belt of Ordovician shale, divided by an elongated area of underlying limestone exposed in an anticline, crosses the northwest corner of New Jersey. Southeast of the main belt two small areas of shale lie in the Great Valley. The shale in all these areas is underlain by Jacksonburg limestone, and no red shale or other unusual types of sedimentary beds are present. The name Martinsburg shale is therefore appropriately applied to these shales. At Branchville, N. J., at the north end of the anticline exposing limestones in the middle of the main shale belt (Fig. 1), Weller[29] collected 4 species of Normanskill graptolites in shale which lies 50-75 feet above the Jacksonburg limestone. The Jacksonburg at this locality contains a lower Trenton fauna, and Weller concluded that the overlying Normanskill graptolites here are of middle Trenton age since they directly overlie the lower Trenton. The pres-

[28] Behre, Charles H., Jr.: 1927. Slate in Northampton County, Pa.: Pa. Topog. and Geol. Surv. Bull. M9, Pl. 2.

[29] Weller, Stuart: 1903. Paleozoic faunas: N. J. Geol. Surv. Rept. on Paleont., 3, p. 52.

ence of Normanskill graptolites in shale above the Chambersburg or Jacksonburg limestone, therefore, does not necessarily place the shale in the Taconic sequence. The exact position of the Normanskill fauna in the stratigraphic column can not be determined at the type locality in eastern New York because it is not associated with fossiliferous carbonate rocks in which the type stratigraphic section is established. It has been generally considered to be of Chazy age.

The Coopers,[80] who have recently studied the stratigraphy of the Athens shale of Virginia which carries the Normanskill fauna, conclude that "The Athens in Virginia, previously regarded as Chazyan, is laterally continuous with beds containing a post-Chazyan fauna.... The Normanskill shale of New York, faunally and lithologically related to the Athens shale, is also probably post-Chazyan, as was originally believed by Ruedemann." Ruedemann[81] originally placed the Normanskill in the Trenton. This accords with Weller's determination of middle Trenton age for the Normanskill in New Jersey. In New York, southwest of Albany, the Taconic sequence has been mapped, and is separated from shales of the Great Valley, which are approximately equivalent to the Martinsburg shale, by a hypothetical thrust fault.[82] The shales of the Taconic sequence are there described as closely folded, slickensided, broken by minor faults, and cut by calcite veins, whereas the shales of the Great Valley, to the west, are little disturbed. No major fault was observed between these two groups of shales of approximately the same age, but the faunas of the two groups are so diverse and unrelated that the two shales are believed to have been deposited in widely separated parts of the basin, or in separate troughs, and to have been brought into juxtaposition by overthrusting. Southward, at the Helderberg escarpment, these two groups of shales and the separating hypothetical fault are covered by sediments of Silurian (Manlius) and Devonian age, and the fault is therefore pre-Silurian, or Taconic, in age.

[80] Cooper, Byron W., and Cooper, G. Arthur: 1946. Lower Middle Ordovician Stratigraphy of the Shenandoah Valley, Virginia: Geol. Soc. Amer. Bull., 57, p. 108.

[81] Ruedemann, R.: 1901. Hudson River beds near Albany and their taxonomic equivalents: N. Y. State Mus. Bull. 42, p. 551.

[82] Ruedemann, Rudolph: 1930. Geology of the Capitol District: N. Y. State Mus. Bull. 285, Geological map.

Detached Shale Areas South of the Main Shale Belt.

In Pennsylvania and New Jersey several detached areas of Ordovician shale lie south of the main shale belt. Most of the areas lie north of the belt of Triassic rocks, but several areas of shale in Pennsylvania are south of the Triassic. In New Jersey, 2 areas of Ordovician shale within the Jersey Highlands are enclosed in a syncline along Musconetcong River. The shale in these areas is gray, argillaceous, and is underlain by Jacksonburg limestone. It is therefore Martinsburg and not a part of the Taconic sequence. Three areas of Ordovician shale, associated with Paleozoic limestones, occur south of the Jersey Highlands, on the north border of the down-faulted Triassic rocks. These shale areas are shown on the geologic map of the Raritan folio.[33] The shale in all three areas is largely bright-red in color. The eastern area, which lies north of Gladstone, is shown on the Raritan geologic map as faulted on all sides. A small area of shale south of Annandale is also shown as faulted on all sides. The other area is northeast of Jutland (Fig. 1). The writer accompanied Henry B. Kümmel in an examination of the rocks in the vicinity of Jutland. The shale lacks the uniform argillaceous character of the Martinsburg. Besides bright-red shale there are present hard ridge-making sandstones, thin-bedded limestone banded with slate, and limestone conglomerate. The sequence of beds observed by the writer is as follows, although the limestones in the upper part of the section may be repeated by folding:

Sequence of Beds at Jutland, N. J.

	Feet
Red shale.	
Limestone conglomerate, in part edgewise conglomerate of slabby limestone and in part composed of pebbles of limestone with glassy quartz grains.	5±
Siliceous banded limestone.	10±
Red and gray shale.	?
Thin-bedded limestone (1-inch beds) rhythmically banded with shale.	10±
Limestone conglomerate of pebbles of banded limestone and limestone containing glassy quartz grains.	5
Concealed.	?
Thin-bedded red shale, hard green shale with thin fine-grained sandstones, and green spotted shale.	?
Dark gray shale and thin sandstone (contains graptolites of Normanskill age).	?
Weller[34] collected from these lower beds 14 species of 4 different genera of Normanskill graptolites.	

[33] Raritan folio, U. S. Geol. Surv. Geol. Atlas No. 191, 1914.
[34] Weller, Stuart: idem, p. 58.

This is a more representative Normanskill fauna of the Taconic sequence than the sparse fauna collected at Branchville.

The shale in the Jutland area is shown on the Raritan geologic map as faulted on its north side but not on its east side, where a narrow band of Jacksonburg limestone is mapped between the shale and the older limestone. In the text of the folio report and in a report[35] by Weller on all the known Jacksonburg limestone areas in the State, this area of Jacksonburg is not mentioned, and no such fossiliferous limestone was observed by the writer at this contact. It therefore may be a fault contact. The shale in the Jutland area closely resembles in lithologic character and faunal content the shales in the main shale belt in Pennsylvania between Susquehanna and Lehigh Rivers which have been tentatively classed as the "Taconic sequence." The shales in all three detached areas just described south of the Jersey Highlands, therefore, are probably in fault contact with the Paleozoic limestones and are small klippen of the "Taconic sequence" resting on older limestones, preserved in a down-fold on the south side of the Highlands adjacent to the down-faulted Triassic sedimentary rocks. In eastern Pennsylvania 2½ miles east of Doylestown,[36] a small area of shale in an uplifted fault block within the belt of Triassic rocks contains red shale, green blocky cherty shale, and hard sandstone, and was called Cocalico phyllite in the report because of its somewhat lithologic similarity to the shale near Manheim. It is in fault relation to the adjacent Conococheague limestone. From its lithology and location (Fig. 1) it may well be a small fault block of the "Taconic sequence" similar to the Jutland area.

In the vicinity of Manheim, Pennsylvania, (Fig. 2) a large area and several smaller outlying areas of Ordovician shale lie on the Beekmantown limestone. These areas contain beds of purple and green shale with associated hard sandstone, and because of this unusual lithology and the added fact that the shale rests unconformably on Beekmantown limestone, it was named Cocalico[37] instead of Martinsburg. A few graptolites collected from the shale were tentatively assigned by Ulrich to the Nor-

[35] Weller, Stuart: idem.

[36] Geology and mineral resources of the Quakertown-Doylestown district, Pa.-N. J.: U. S. Geol. Surv. Bull. 828, p. 28 and pl. 1, 1931.

[37] Atlas of Pennsylvania: Pa. Topog. and Geol. Surv. No. 178, New Holland quadrangle, 1926; No. 168, Lancaster quadrangle, 1930.

manskill. Fossiliferous limestone that lies between the shale and the underlying Beekmantown limestone was observed at two places. The fossils were pronounced by Ulrich to be of early Trenton or Black River age. There is no evidence of a thrust fault at the borders of these shale areas, but for a short distance along the south border, north of Mt. Joy, local normal faulting is indicated. The shale is not contorted or much disturbed at its margin, and appears from observed relations to lie in a syncline and to have been deposited in situ, unconformably on Beekmantown limestone and in part on thin fossiliferous argillaceous limestone of early Trenton age. The shale has some lithologic features that suggest the "Taconic sequence." The shales which suggest the "Taconic sequence," however, are purple and not bright red. The purple and green shales and hard sandstone, if they were deposited in situ, lie near the base of the shale. In a previous paper the writer[88] regarded them as probably of volcanic origin, related to the basaltic lava flow near the base of the shale at Jonestown, Pa., previously described. The rocks containing that flow are in this paper included in the "Taconic sequence," and it is possible that the shales in the Manheim area also may be "Taconic" and rest in fault position on the older limestones.

North of the belt of down-faulted Triassic rocks, six miles north of the area of Cocalico shale just described, an area of similar shale extends eastward from Schaefferstown to the southwest end of South Mountain. The shale is largely gray, but has at its borders purple, red, and green shale and hard sandstone. It overlies Conococheague and Elbrook limestones. The shale is injected by quartz and makes high hills that rise sharply out of the surrounding limestone lowland. This area of shale is separated from the area of Cocalico shale near Manheim by the Triassic rocks which are only six miles wide at this point, and it is probable that the two areas of shale are connected beneath the Triassic rocks. Further field study is necessary to determine whether these two areas of Cocalico shale are part of the "Taconic sequence" or are Martinsburg shale.

Gray shales in a long narrow area in the limestone lowland west of Reading and in smaller areas southwest of that city are much crumpled and crushed and lie unconformably on Beek-

[88] Stose, George W., and Jonas, Anna I.: idem, pp. 522-524.

mantown, Conococheague, and Elbrook limestones. No red or purple shale was observed in these areas. The crumpling of the shales is believed to have been caused by folding into tight overturned synclines and the shales are believed to be Martinsburg in the overridden block, unconformably deposited on the older limestones. The long, narrow shale band west of Reading extends nearly to the main shale belt at Wernersville, and is probably a syncline offshoot of that area.

In the Oley Valley, 6 miles east of Reading, soft gray shale and underlying cement rock of the Jacksonburg limestone, in gentle synclines, rest on Beekmantown limestone, and are certainly Martinsburg shale. A very small area of shale unconformably overlies Conococheague limestone at Limeport,[89] 8 miles south of Allentown, Pa. It is also probably Martinsburg.

*Relation to the Martic Overthrust.**

The writer has suggested in this paper that rocks of the Taconic sequence occur in the shale belt of eastern Pennsylvania and possibly in detached smaller areas to the southeast in Pennsylvania and New Jersey, and that these rocks lie in thrust position on typical Martinsburg shale and older limestone. If this interpretation is correct, the argillaceous rocks of the "Taconic sequence" must have been deposited contemporaneously with early Paleozoic argillaceous and carbonate facies of the Great Valley, but were laid down far to the southeast of their present position. In areas south of the Ordovician shale in Pennsylvania, the carbonate facies with Lower Cambrian quartzite at the base overlies pre-Cambrian rocks which are exposed in several anticlines. The southeastern border of this Paleozoic folded belt is the Martic overthrust, which lies southeast of Chester, Lancaster, York, and Hanover Valleys (Fig. 1). The Martic overthrust block is overlapped on its southeast side by sediments of the Coastal Plain.

The Martic overthrust block contains a series of closely folded crystalline schists. Anticlines in the schist expose early pre-Cambrian Baltimore gneiss and overlying Setters quartzite and Cockeysville marble. The crystalline schists are an argillaceous series with quartzose beds and some beds of marble. They contain also metabasalt and aporhyolite flows

[89] Stose, George W., and Jonas, Anna I.: idem, pp. 518–520.

* Anna J. Stose has contributed to this discussion.

and purple and green phyllite, in part of tuffaceous origin. In lithologic character, therefore, the schists resemble the "Taconic sequence," but they are greatly metamorphosed and contain a larger proportion of volcanic rocks. The crystalline schists have yielded no fossils and their age is not definitely known. In Pennsylvania they are overlain by the Peach Bottom slate with Cardiff conglomerate at the base, but no fossils have been found in these rocks. In Virginia the Arvonia slate with a quartzose conglomerate at the base overlies the Peters Creek formation of the crystalline schist series. The Arvonia slate, which is similar in lithology and stratigraphic relation to the Peach Bottom slate of Pennsylvania, contains fossils of Upper Ordovician age. The crystalline schist series, therefore, is older than Upper Ordovician and may be of early Paleozoic age, as is the Taconic sequence.

On their northwest border the crystalline schists overlie rocks of the Great Valley ranging from Harpers phyllite and Vintage dolomite of Lower Cambrian age to Conestoga limestone in part of Ordovician age. This contact is believed by the writer to be an overthrust, the evidence for which conclusion is summarized in a recent report.[40] West of the plunging end of the Mine Ridge anticline, which exposes Lower Cambrian quartzites and underlying pre-Cambrian rocks, the overthrust rocks of the Martic block also are folded into an anticline with the overridden rocks. The major part of the folding, which is of late Paleozoic age, therefore, is later than the overthrust. The Conestoga limestone, which contains fossils of Beekmantown age in the eastern part of Chester Valley, is the youngest rock which is overridden by the Martic overthrust, so that the thrust is post-Beekmantown. It may possibly be of pre-Silurian age, or Taconic.

In a forthcoming report by the writer and Anna J. Stose,[41] they suggest that the Wissahickon schist in Maryland and southern Pennsylvania rests with overthrust relations on the Cockeysville marble and Setters quartzite exposed on the flanks of anticlines of Baltimore gneiss, and that the Setters quartzite and Cockeysville marble may be of Lower Cambrian age and

[40] Stose, Anna J., and Stose, George W.: 1944. U. S. Geol. Surv. Prof. Paper, 71-78.

[41] Stose, Anna J. and George W.: Geology of Frederick and Carroll Counties, Maryland: Md. Geol. Surv. (In press.)

part of the Great Valley sequence which the crystalline schists have overridden. If this interpretation is correct, the Martic overthrust block is an allochthone which is buried on the southeast by the sediments of the Coastal Plain. On the basis of the lithologic resemblance and the meager knowledge of the age of the crystalline schists and the Martic overthrust, it seems possible that the schists may be the metamorphic equivalent of the Taconic sequence, and that the Hamburg klippe and related smaller klippen in the Great Valley may have originated in the Martic allochthone.

The suggested relationship of unmetamorphosed rocks of the "Taconic sequence" in the Hamburg klippe to metamorphosed schists of the Martic overthrust block is similar to that which has been suggested for the different parts of the overthrust Taconic sequence in western New England and eastern New York. The Taconic sequence in that area is believed[42] to have been deposited east of the Green Mountains contemporaneously with early Paleozoic quartzite and carbonate facies now exposed on the west flanks of the Green Mountains. During the Taconic deformation the eastern argillaceous sequence was thrust westward and now lies on the carbonate sequence and associated Ordovician shales of the Great Valley. The rocks in the western part of the klippe that lie largely in eastern New York are not metamorphosed, but those in the eastern part, in the Taconic Range, are mildly metamorphosed. In Mount Greylock and the Hoosac Range, farther to the east, the metamorphism is greater. The Hoosac schist and Rowe chloritoid schist of that area resemble the crystalline schists of the Martic overthrust block. The rocks of the Taconic overthrust block, as in those of the Martic block, have been deformed by folding and thrust faulting and this later deformation has confused the overthrust relations. The authors of the report on the Taconic quadrangle[43] were not in accord as to whether the Hoosac and Rowe schists rest with sedimentary contact on the pre-Cambrian rocks in the Hoosac Range or whether they originated farther to the east and attained their present position by overthrusting. Cady[44]

[42] Prindle, L. M., and Knopf, E. B.: 1932. Geology of the Taconic quadrangle: AMER. JOUR. SCI., (5), 24, p. 297.

[43] Prindle, L. M., and Knopf, E. B.: idem, p. 292.

[44] Cady, Wallace M.: 1945. Stratigraphy and structure of west-central Vermont: Geol. Soc. Amer. Bull., 56, 567-569, and Fig. 5.

believes that "the Taconic allochthone must have been transported from the southeast [that is, southeast of the Green Mountain axis] although a root zone has not been established there."

Conclusions.

The name Martinsburg shale should be restricted to shales and sandstones lithologically similar to and having the same age limits as those in the type locality in the Massanutten syncline in West Virginia and in adjacent parts of Virginia, Maryland, and Pennsylvania. In eastern Pennsylvania the shales that are believed to be typical Martinsburg include a thick series of uniformly soft, gray argillaceous shale which contains a fauna of middle Eden age, some beds of which have been altered to a commercial slate, overlain by sandy shale and sandstone which contains a Pulaski fauna. The Martinsburg shale normally lies on the Chambersburg or equivalent Jacksonburg limestone, but on the southeast border of the basin, south of Harrisburg and eastward to Reading and Allentown, typical Martinsburg shale unconformably overlaps the Beekmantown and in places rests on the Conococheague and Elbrook limestones.

The main shale belt in eastern Pennsylvania contains rocks which are lithologically and faunally different from those of the typical Martinsburg and have different age limits. Their fossils show that they range from Beekmantown to Trenton. They may contain beds older than Beekmantown. The name Martinsburg shale should not be applied to these rocks and the mappable units should receive other names. These distinctive rocks resemble in many respects the Taconic sequence of eastern New York and western New England. In places they are known to be in fault relations to the adjacent Martinsburg shale and underlying limestones, and were evidently deposited in a different basin, or distant part of the same basin, from that in which the Martinsburg was laid down.

The writer suggests, therefore, that the shale sequence present east of Susquehanna River, which is unlike the typical Martinsburg shale, belongs to the "Taconic sequence" and overlies with fault relations the Martinsburg shale and underlying limestones. The thrust block of the "Taconic sequence," called the Hamburg klippe and other smaller related klippen, are

part of an argillaceous sequence which has been thrust northwest over the carbonate sequence of the Great Valley during Taconic orogeny. The north border of the Hamburg klippe has been in part covered by deposition of Lower Silurian sedimentary rocks. The writer suggests also that the crystalline schists of the Martic overthrust block may be the metamorphic equivalent of the "Taconic sequence," and that the Hamburg klippe and smaller klippen are erosional remnants of the unmetamorphosed part of the Martic overthrust block.

WASHINGTON, D. C.

USE OF ROCK "NORMS" IN GEOPHYSICAL INVESTIGATIONS.

REGINALD A. DALY.

ABSTRACT. From the norm derived from a good chemical analysis of an igneous rock the density and cubic compressibility of that rock, if holocrystalline, pore-free, and at room temperature, can be closely calculated, and that through a wide range of pressures. This "norm" method, available also in the case of materials originally represented by well-analyzed rock-glasses and vesicular lavas, has been used to give: (1) the density and compressibility of a Pre-Cambrian basement complex, illustrated by Sederholm's average analysis of all the exposed rocks of Finland; and (2) similar data regarding the materials corresponding to world-average analyses of 18 principal eruptive types. The results of the computations are recorded in tables, which, it is hoped, may give the geophysicist a basis on which to found deductions regarding the nature of the outer earth-shells. It is pointed out that his chief difficulty in using the tables is the existing inadequacy of experimental evidence concerning the coefficients of thermal expansion for rocks at high pressures.

PURPOSE OF THE INQUIRY.

THE velocities of the seismic waves are being used to deduce the lithological character of the earth-shells as now constituted. In making that effort it is necessary to know for each depth the velocity of the longitudinal wave (V_p), the velocity of the transverse wave (V_s), the implied value of Poisson's ratio (σ), and also both the density (ρ) and the "true" cubic compressibility (β) of the material. Poisson's ratio, generally ranging between 0.2 and 0.3, is got from the simple equation:

$$\left(\frac{V_p}{V_s}\right)^2 = \frac{2\sigma-2}{2\sigma-1}.$$

V_p equals a quantity A divided by the square root of the product β x ρ. A is determined by the value of σ. For selected values of σ and V_p/V_s, those of A are given in the second column of Table 1, according to computations kindly made for the writer by Prof. Francis Birch of the Harvard geophysical laboratory.

The rock material that best fits V_p at a given level in the earth is, then, one that would have the proper density and com-

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TABLE 1.—Giving the Factor A in Relation to Poisson's Ratio.

σ	A	V_p/V_s
.20	1.414	1.634
.21	1.400	1.651
.22	1.385	1.669
.23	1.370	1.689
.24	1.356	1.710
.25	1.342	1.732
.26	1.327	1.756
.27	1.313	1.782
.28	1.299	1.809
.29	1.285	1.839
.30	1.271	1.871

pressibility at the pressure and temperature there ruling. For each rock type the density can be rather closely estimated. The chief difficulty facing the diagnostician is to arrive at a good value for the compressibility. It is to be hoped that in the future direct measurements of compressibility of each important rock type, when subjected to high pressure and high temperature simultaneously can be made. Meantime thought can be guided by comparing the available results of measurement at room temperature, even though so little is known about the quantitative effect of high temperature on the elastic properties of rocks and rock minerals. The present paper describes a promising way of rapidly increasing the low-temperature data concerning individual specimens. The new method is also available for finding the high-pressure, low-temperature compressibilities of holocrystalline materials represented by: (a) the average chemical compositions of the voluminous rock species occurring in the earth's crust; and (b) analyses of obsidians, tachylites, and lavas in general.

This new method was suggested to the writer from the announcement of Adams and Williamson (1923, p. 517), that the compressibility of a holocrystalline rock at high pressure can be closely calculated from the known volumes and compressibilities of the constituent minerals. Such "mode" compressibilities were computed by them for three granites, two diabases, and one gabbro. Later Adams and Gibson (1929, p. 720) added two other diabases to the list. At 10,000 bars the ratio of measured compressibility to mode compressibility was, in average for the eight specimens, 1.000 to 0.985—the ratio for the granites alone being 1 to 1. With analogous com-

parisons for the same eight specimens the present writer has come to the conclusion that "norm" or "standard" minerals can be used, the errors being in general smaller than those incurred when the mode method is employed. Incidentally, with each determination of compressibility the "norm density" of the corresponding holocrystalline, pore-free, and water-free rock type has been calculated. In each case the margin of error is believed to be small.

Thanks are due to Professor Birch, for helpful, critical reading of this paper when in manuscript form.

THE NORM METHOD.

First, some details regarding the method itself are in order. Only "superior" analyses, singly or in groups, are employed. From many of them certain minor constituents are omitted, as of negligible influence on the values of either compressibility or density. Water is also omitted, because of general doubt as to how much of it is native to any given material. The omission seems justified when the aim is merely to compare the essential characteristics of the different rock types with those expected in the case of an assumed material composing a particular earth-shell. After all the omissions each analysis is reduced to 100.00. Then the norm is computed and it also is reduced to 100.00. Room temperature (20°) is assumed. The adopted compressibilities of eight out of the fourteen norm (standard) minerals at 20° and at 1 bar, 2000 bars, 10,000 bars, 20,000 bars, and 30,000 bars are those directly measured by L. H. Adams and colleagues (1923, 1927), or else have been extrapolated from the pressure-compressibility curves derived from their experiments. The values given for albite and anorthite have been estimated from the results accruing from their experiments on plagioclases of intermediate composition. Their maximum pressure ranged from 7840 to 12,000 bars. Extrapolation to 30,000 bars is evidently bold, but Prof. P. W. Bridgman's recent direct measurements on some of the mineral species concerned, exposed to pressures up to about 50,000 bars, seem to show that the extrapolations described are not with errors too great to invalidate the new method. Special weight is also given to (unpublished) direct measurements for orthoclase (sanidine), diopside, hypersthene, and olivine by Professor Bridgman, whose new apparatus gave

highly trustworthy compressibilities for 10,000, 20,000, and 30,000 bars. In al writer has attempted to make smooth pre curves combining the Bridgman values w been reported—to 12,000 bars—by Adaı

The compressibilities of nepheline, ch apparently not measured at any pressure, in the light of analogies. These guesse considerably in error, but, because of the each of the three compounds in the mater the errors in the calculated compressibiliti be small.

Table 2 gives specific volume and β different pressures. The "Betas" repres sibilities, each being the per-bar change of pressure. To get those values small cha in the compressibilities originally issued leagues, which were referred to volume a the values coming from Bridgman, who ı ume at 1 bar.*

TABLE 2.—Specific Volumes (S. V.) and "1 (Beta) of Norm Minerals at 20° and at

	1		2,000		10,000	
(bars) Pressure	S.V.	Beta x 10⁶	S.V.	Beta x 10⁶	S.V.	Beta x 10⁶
Quartz	.377	2.70	.375	2.61	.367	2.20
Orthoclase	.394	2.12	.392	2.06	.386	1.85
Albite	.384	1.90	.382	1.86	.377	1.70
Anorthite	.362	1.09	.361	1.08	.357	1.04
Nepheline	.385	2.00*	.382	1.95*	.378	1.80*
Corundum	.249	.38	.249	.38	.248	.37
Diopside	.305	1.07	.304	1.04	.302	.95
Hypersthene	.294	1.04	.293	1.02	.291	.97
Olivine	.303	.85	.302	.84	.300	.82
Magnetite	.193	.55	.193	.54	.192	.51
Ilmenite	.210	.56	.210	.55	.208	.52
Apatite	.312	1.09	.311	1.07	.309	1.00
Chromite	.227	.60*	.227	.60*	.226	.59*
Troilite	.208	1.60*	.207	1.57*	.205	1.45*

* Rough estimate of value.

* By inadvertence the compressibilities given in "Igneous Rocks and the Depths of the Earth" "true"; they are really the one-bar changes of v volume at 2000 bars. The errors involved are s the margin of experimental uncertainty about particular compressibility.

Before noting specific results won by the norm method, the validity of the method itself will be tested.

Adams and Williamson (1923) and Adams and Gibson (1928) have carefully measured the compressibilities of 3 granites, 4 diabases, and a gabbro at 20° and at 2000 bars and 10,000 bars. For all of them the norm compressibilities have been computed and recorded in Table 3. At 2000 bars the measured values are, in average, 10 per cent higher than the norm values. At 10,000 bars the corresponding excess is only about 2 per cent. As already remarked, the average "mode"

TABLE 3.—Comparison of Norm and Measured Compressibilities ($x\ 10^6$) at Two Pressures, Room Temperature.

Pressure	2000 bars		10,000 bars	
	Norm	Measured	Norm	Measured
Westerly granite*	1.78	1.99	1.86	1.87
Washington granite	1.85	2.27	1.65	1.76
Stone Mountain granite*	2.05	1.96	1.78	1.81
New Glasgow gabbro	1.12	1.20	1.06	1.15
Palisades diabase*	1.33	1.54	1.23	1.30
Sudbury diabase	1.37	1.37	1.21	1.25
Whin Sill diabase*	1.40	1.70	1.28	1.26
Maryland diabase	1.25	1.23	1.17	1.07
Average of 8	1.51	1.66	1.40	1.43
Average, 3 granites	1.88	2.07	1.76	1.81
Average, 4 diabases	1.34	1.46	1.22	1.22

* Rough estimate of value.

compressibility of the 8 rocks at 10,000 bars was found to be 3.5 per cent less than the average measured compressibility. The positive sign of the difference in the first comparison is reasonably referred to the incomplete closure of empty spaces in the rocks, other than the "realized" cleavages of the constituent minerals. On the other hand, the fact that the mode compressibility averages 3.5 per cent less than the measured compressibility is probably due to errors in estimating the proportions of minerals actually present in the rocks. Such estimates are notoriously hard to make with great accuracy. It thus appears that in the calculation of compressibility of a crystalline rock it is better to use the norm rather than the mode.

If the two-per cent excess of the measured compressibility at 10,000 bars could be proved real and not caused by errors of measurement or computation, one might well suppose that even at 10,000 bars the original pores of a rock at 20° are not entirely closed during the limited time of a compressive test in

the laboratory. That possibility becomes less incredible when one remembers the increase of rock strength when exposed to high all-sided pressure, and also allows for the slowness of "annealing" or plastic flow at room temperature. Such flow, with complete closure of pores, might, however, be expected in the case of a crystalline rock exposed for millions of years to the temperature and pressure characterizing any depth in the earth exceeding five or ten kilometers. It seems even possible that the cleavages of the mineral components in rocks that crystallized at such depth would be merely potential and not "realized."

If there is reason to suspect that a deep-seated rock carries enough alumina and other constituents necessary for the crystallization of garnet, then this mineral should, if possible, be properly proportioned and entered in the list of norm minerals. The difficulty of fixing the mineral composition of any earth-shell assumed to be rich in garnet, such as the commonly-suggested eclogitic, is apparent. For a layer of that kind the norm method, based on the "standard" minerals of Table 1, might lead to gross diagnostic error. Eclogite is a theoretically possible phase of the "gabbroic" sublayer of the earth's crust, but garnet does not appear as an essential constituent of any large mass of visible igneous rock and seems to be practically absent in stony meteorites. It is therefore probable that the material to which the norm method cannot be applied represents no more than a small fraction of the whole silicate mantle surrounding the "iron core" of our planet.

Needless to say, the worth of the norm method can be finally tested only after many more individual specimens of rocks and rock minerals have been actually measured at high pressures. Moreover, it is best regarded as a supplementary, rather than a replacing, method, and specially useful in cases where the fundamental and more direct means of finding compressibilities cannot be employed.

ROCK TYPES OF CONCERN TO THE GEOPHYSICIST.

Norms.—Because of considerable variation in the chemical composition characterizing any of the standard species of eruptive rocks, it is hard to choose any one analysis as typical. In making comparisons with intent to identify the material of any of the invisible earth-shells it seems to the writer wise to

use world averages for each rock type. Such averages, representing what may be called "collective opinion" on this subject of typical composition, were struck thirteen years ago (Daly, 1933, p. 9) but are believed not subject to important changes if the analyses published since 1933 were included. From the averages actually computed the respective norms have been calculated and entered in Tables 4, 5, and 6.

TABLE 4.—Norms of Average Analyses.

	1	2	3	4	5	6
	Surface rocks of all Finland (basement complex)	546 granites	40 granodiorites	55 quartz diorites	70 diorites	12 anorthosites
Quartz	25.27	28.85	20.46	18.01	9.12	....
Orthoclase	21.18	24.50	16.68	12.24	12.24	4.45
Albite	26.21	29.40	31.48	28.84	28.84	27.03
Anorthite	15.85	9.19	18.90	23.36	24.75	58.74
Nepheline	....	....	....	....	....	2.41
Corundum	....	1.02	....	....	....	....
Diopside	.46	....	2.04	1.79	6.06	2.66
Hypersthene	8.16	3.65	6.58	10.21	12.21	2.77
Magnetite	1.85	2.32	2.55	3.71	4.64	1.68
Ilmenite	.76	.76	1.06	1.22	1.52	.30
Apatite	.31	.31	.30	.62	.62	.01
	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 5.—Norms of Average Analyses.

	7	8	9	10	11	12
	50 fresh gabbros	90 diabases	80 plateau basalts (Washington analyses)	28 Hawaiian basalts	10 oceanites	5 bronzitites
Quartz	....	1.44	1.20	1.55	....	....
Orthoclase	6.12	6.12	8.35	8.34	2.22	1.67
Albite	20.97	26.20	20.95	20.48	10.98	8.68
Anorthite	34.21	25.58	25.60	24.19	15.94	6.97
Diopside	12.61	14.71	18.80	21.35	15.91	34.87
Hypersthene	13.42	16.87	19.25	18.90	14.07	41.51
Olivine	4.29	....	....	....	33.83	7.30
Magnetite	4.41	5.57	5.10	3.71	3.24	3.70
Ilmenite	3.04	2.89	5.15	5.93	3.19	.15
Apatite	.93	.62	.60	.60	.62	.15
	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 6.—Norms of Average Analyses.

	13	14	15	16	17	18	19
	12 websterites	10 dunites	8 harzburgites	13 lherzolites	5 wehrlites	20 achondritic meteorites	63 stony meteorites
Orthoclase	2.22	.22	.55	1.11	3.36	1.65	1.11
Albite	3.67	1.06	2.62	5.26	10.03	5.73	7.88
Anorthite	6.68	1.65	1.94	10.04	9.24	13.00	3.90
Diopside	35.29	1.31	3.49	5.48	22.70	18.27	3.37
Hypersthene	40.16	5.83	8.76	10.50	11.72	40.42	28.24
Olivine	8.10	85.61	78.26	63.90	36.27	18.77	46.29
Magnetite	3.72	4.20	4.14	3.25	5.14	....	1.39
Ilmenite	.15	.03	.15	.15	1.23	....	.31
Apatite	.01	.09	.09	.31	.31	....	.98
Chromite	....	....	....	....	....	.67	.63
Troilite	....	....	....	....	....	1.49	5.90
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Densities.—In 1935 the writer (Daly, 1935, p. 659) computed the one-bar densities of some of the world types from their norms, using a convention not justified by theory but yet giving highly satisfactory results. On the present occasion the norm method is again used, but the densities are now found by taking the reciprocal of each total specific volume, a quantity determined on the way to calculating the compressibility. The results obtained with this theoretically more justified method are given for five different pressures in Table 7. It should be

TABLE 7.—Norm Densities of Rocks and Meteorites, Calculated From World-Average Analyses (Materials Holocrystalline, Anhydrous, and Pore-Free). 20° C.

Averages from:	Densities at:				
	1 bar	2000 bars	10,000 bars	20,000 bars	30,000 bars
546 granites	2.690	2.703	2.745	....	....
40 granodiorites	2.735	2.747	2.787	....	....
55 quartz diorites	2.787	2.801	2.839	2.883	....
70 diorites	2.832	2.857	2.893	2.939	....
50 fresh gabbros	2.966	2.974	3.005	3.040	3.070
90 diabases	2.976	2.984	3.014	3.050	3.083
30 plateau basalts (Washington analyses)	3.065	....	3.100	3.131	3.160

Averages from:	Densities at:				
	1 bar	2000 bars	10,000 bars	20,000 bars	30,000 bars
23 Hawaiian basalts	3.056	....	3.095	3.130	3.152
10 oceanites	3.164	....	3.208	3.235	3.265
12 anorthosites	2.752	2.761	2.795	2.830	....
5 bronzitites	3.285	....	3.320	3.350	3.375
12 websterites	3.282	....	3.317	3.347	3.372
10 dunites	3.370	....	3.400	3.425	3.445
8 harzburgites	3.350	....	3.380	3.405	3.425
13 lherzolites	3.260	....	3.295	3.320	3.342
5 wehrlites	3.250	.....	3.285	3.311	3.333
20 achondritic meteorites (iron-free)	3.250	....	3.285	3.310	3.331
63 stony meteorites (iron-free)	3.335	....	3.365	3.390	3.410
Surface rocks of all Finland (Sederholm average analysis)	2.717	2.730	2.760	....	....

noted that, when this second method is tested in cases of individual rocks for which good analyses and density measurements are available, the method makes each density about 1 per cent too low. However, since the great majority of the published analyses are, unfortunately, not accompanied with statements of the corresponding specific gravities, thoroughly adequate comparison between norm and measured densities is not now possible. It is truly remarkable that many petrologists, necessarily occupied with the role of density differences in magmatic differentiation, have sinned in this respect. Here there is room for reform!

Compressibilities.—The compressibilities calculated from the norms are stated in Table 8, here also for five pressures. The values, rounded to the second decimal place, must contain errors, but these are believed in no case to be large. Their smallness is suggested by comparison of the compressibilities found for the four well-studied and comparatively pore-poor diabases named in Table 3. The average norm compressibility of these at 10,000 bars is 1.226×10^{-6} (nearly identical with the average measured compressibility at the same pressure), while the average norm compressibility of the 90 diabases of Table 8 is 1.257×10^{-6}. The difference, 0.031×10^{-6}, is not great and it has the sign expected in view of the fact that the norm density of the four diabases is, in average, 3.036 and thus implying a mean compressibility somewhat lower than that of the 90 diabases with their average norm density of 3.014.

TABLE 8.—"True" Norm Compressibilities of World-Average Rock Types (Holocrystalline and at 20°C.) x 10^6.

	At 1 bar	At 2000 bars	At 10,000 bars	At 20,000 bars	At 30,000 bars
Averages from:					
546 granites	2.07	2.00	1.77	...	...
40 granodiorites	1.87	1.82	1.63	...	...
55 quartz diorites	1.76	1.72	1.55	1.37	...
70 diorites, excluding quartz diorites	1.61	1.58	1.44	1.29	...
50 fresh gabbros	1.31	1.29	1.20	1.11	1.04
90 diabases	1.39	1.37	1.26	1.15	1.07
30 plateau basalts (Washington analyses)	1.29	...	1.19	1.11	1.04
28 Hawaiian basalts (Washington analyses)	1.32	...	1.20	1.10	1.02
10 oceanites	1.11	...	1.03	.97	.92
12 anorthosites	1.38	1.36	1.27	1.19	...
5 bronzitites	1.08	...	1.00	.93	.87
12 websterites	1.08	...	1.00	.93	.87
10 dunites	.89	...	.85	.82	.80
8 harzburgites	1.00	...	.94	.89	.85
13 lherzolites	1.01	...	.95	.90	.86
5 wehrlites	1.11	...	1.03	.96	.90
20 achondritic meteorites	1.10	...	1.02	.95	.89
68 stony meteorites	1.09	...	1.01	.95	.89
Surface rocks of all Finland (Sederholm average analysis)	1.95	1.90	1.70	...	...

APPLICATION OF THE RESULTS.

Densities and compressibilities of Tables 7 and 8 have been computed after making several assumptions: that the various rocks listed are (1) free from pores other than those represented by the "realized" cleavages of the minerals named in Table 1; (2) freed from water; and (3) at room temperature. As already observed, empty cavities are not likely to persist at depths in the earth exceeding a few kilometers, where pressure, temperature, introduction of salts, and lapse of time coöperate in closure. The first assumption should, therefore, not give mental trouble to the seismologist who tries to match earth-shells with known types of rock. How far the neglect of water-content involves errors in deduction of both density and compressibility cannot be clear until new, special experiments on the problem are made in the high-pressure laboratory. However, it is rather obvious that allowance for one per cent of water would not essentially change the norm-derived values of Tables 7 and 8.

Much more serious is the difficult question as to the amount of correction demanded when allowance is made for simultaneously-acting high temperature and high pressure. In the case of density what is virtually needed is a long series of new experiments on the thermal expansion of standard rocks at great ranges of both pressure and temperature. Equally elusive is choice of the proper temperature coefficients of compressibility at higher and higher temperatures and pressures. Birch and Bancroft (1938, p. 88; 1940, p. 760; 1942, p. 464 and 487; see also Birch, 1943, p. 279) have proved that at low pressure those coefficients, whether for rigidity or compressibility, rise rapidly as the temperature increases, the total effect at 1200° or higher being relatively enormous. On the other hand, a few of their experiments (1940, p. 760) have shown that the temperature effect grows decidedly less as the pressure rises considerably. Bridgman (1913, p. 1, and 1942, p. 399), carrying pressures up to 10,000 kg/cm^2 and later to 50,000 kg/cm^2, at temperatures rising to maximum of 175°, measured the volume changes of many liquids and of their pressure-crystallized equivalents. From his results the present writer computed the corresponding changes in the temperature coefficients, and found them to diminish rapidly as the pressure rose above 5000 bars. Using this principle, the attempt was made to estimate the compressibilities of various peridotites, supposed to be holocrystalline, at the temperature of 1500° and pressure of 30,000 bars. The estimates will be described in a current number of the Bulletin of the Geological Society of America. One purpose of that publication is to emphasize the urgent need of additional measurements of the temperature coefficients of the standard rocks when exposed to conditions like those ruling well below the surface of the earth. If and when such data are in hand, it should be possible to use the coefficients, along with the norm compressibilities of Table 8 in the problem of estimating the compositions of the outer earth-shells.

The paper-in-press above referred to describes steps taken to arrive at reasonable estimates of the densities and compressibilities of some rock types when heated to the vitreous state at pressures ranging from 1 bar to 30,000 bars. The norm density and norm compressibility of each rock at 20° and 1 bar were made the basis for extrapolation, with intent to can-

vass the possibility of magmatic material at the depth of 100 kilometers in the earth. Perhaps, too, the double use of the rock norms may have value in supplementing direct experimentation bearing on the conditions for gravitative crystal-fractionation of magmas and for magmatic stoping, and also bearing on the question whether a continuous or discontinuous substratum of vitreous basalt now underlies the crust of the earth. Even more fundamental with respect to the main thesis of this paper would be experiments able to declare how far the norm method may have to be modified to allow for actual polymorphic changes in minerals exposed to the high pressures at great depth.

The hypothesis that the earth as a whole has the chemical composition of the average meteorite is promising enough to warrant the systematic testing of compressibility and density that belong to different types of meteorites at both high pressure and high temperature. Special laboratory study may yet discover why eclogite or other garnet-bearing material does not appear among the achondritic and chondritic stones of museum collections.

Finally, it may be noted that in any case general use of the norm compressibilities for diagnostic purposes is justified only if that method is found to suggest for each earth-shell a type of rock that would give the seismically-effective rigidity determined by the velocity of the transverse wave running in that shell. Ide (1936), and Birch and Bancroft (1938), have developed an elegant and accurate technique for measuring the rigidity at high pressure and temperature, and it is to be hoped that many more experiments of the kind will be made, thus giving a most valuable check on the compressibility method of diagnosis.

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POSTGLACIAL FOREST SUCCESSION AND CLIMATE IN THE OREGON CASCADES.[1]

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ABSTRACT. The postglacial chronology of pollen profiles from sedimentary columns in the southern Oregon Cascades is revealed by the record of postglacial volcanic activity. The postglacial eruptions are defined by relationship of volcanic ejecta to moraines, glacial striae, and other glacial evidence, and by the occurrence of volcanic glass horizons interbedded in organic sediments or underlying sediments. The most widespread evidence for postglacial volcanic activity is that of the eruption of Mount Mazama, which formed the caldera holding Crater Lake. Its stratigraphic position in relation to the recorded postglacial vegetational succession, the evidence of the fluctuation of lakes in the Great Basin, and its relation to the evidence of early man in south central Oregon suggest that the eruption occurred between 10,000 and 8,000 years ago. Other postglacial volcanic activity is recorded by volcanic glass strata in both organic and inorganic sediments. The recorded vegetational succession supports the evidence offered in 60 other pollen-bearing sedimentary columns throughout the Pacific Northwest for the occurrence of a warm, dry period between 8,000 and 4,000 years ago. The correlation of this dry period with other chronological data in the Pacific Northwest, the Great Basin, eastern North America, and northern Europe, further supports the evidence for a warm, dry, postglacial climatic maximum over much of the north temperate zone.

INTRODUCTION.

ONE of the most striking features of the central Oregon Cascades is the evidence of recent volcanic activity on an extensive scale. The vast expanses of pumice, the lava flows, obsidian cliffs, pillow lavas, and blocks of volcanic ejecta, as yet only slightly weathered and eroded, almost cause one to expect to see smoke pouring from a nearby crater in its final stages of eruption. Some of the volcanic activity responsible for these widely scattered ejecta occurred since the maximum of the last Wisconsin glaciation, and some even during the past few centuries (Williams, 1942, 1944). The record of this volcanic activity and Pleistocene glaciation has provided two important time markers for postglacial history of vegetation and climate in the Oregon Cascades, and in fact, for the entire Pacific Northwest. The pollen-bearing sediments and their interred record of postglacial forest succession offer a means

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of dating relatively a few of the postglacial volcanic eruptions in the area. These local chronological data correlated with those from other areas have enabled the establishment of a relative and general chronology for climate, vegetation, and early man in the Pacific Northwest. Further study and correlation of the available evidence will probably strengthen this tentative chronology and permit the division of postglacial time into a greater number of units.

The most widespread and most obvious evidence for postglacial volcanic activity is that of the eruption of Mount Mazama, which formed the caldera holding Crater Lake in southern Oregon. This great eruption spread a mantle of pumice six inches or more deep over an area of about 5,000 square miles to the north and east of Crater Lake (Fig. 1).

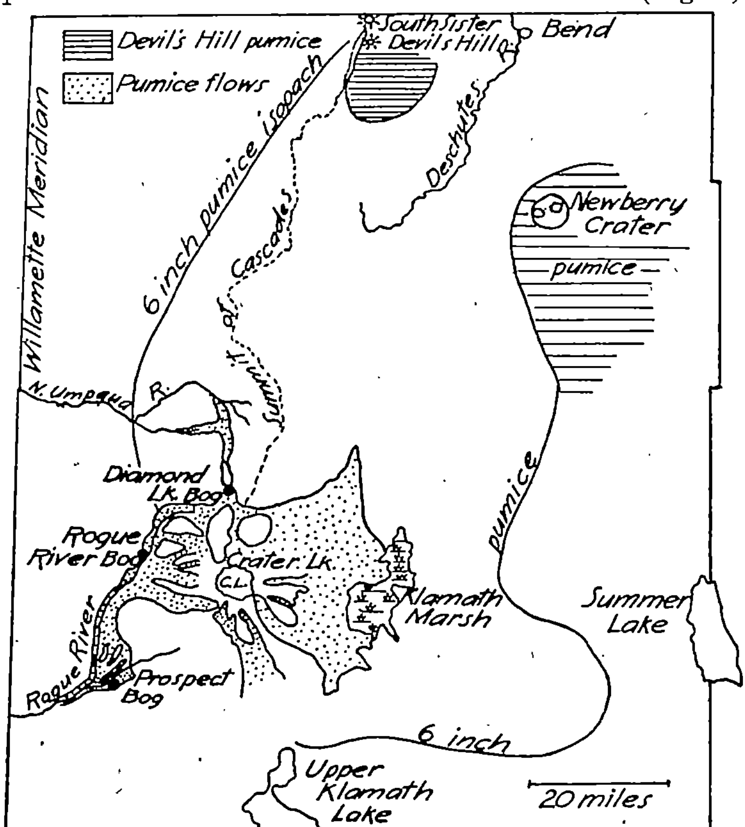


Fig. 1. Map showing the distribution of Mount Mazama pumice. (after Williams).

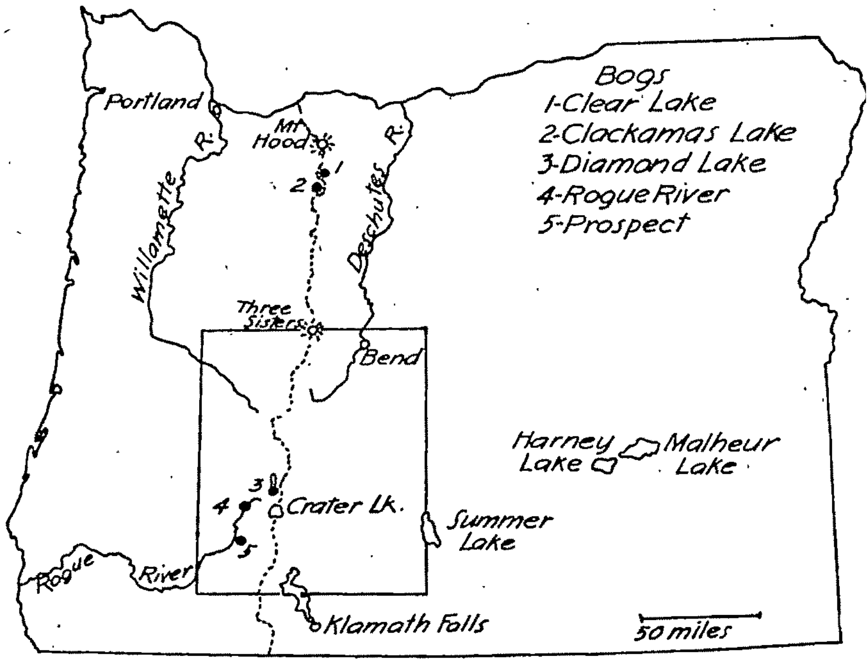


Fig. 2. Map of Oregon showing location of five bogs of this study. The area represented by Fig. 1 is indicated by the superimposed rectangle.

The prevailing winds during the eruption were from the south and west as indicated by the almost complete absence of air-borne pumice on the south and west slopes of Crater Lake Mountain, even near the rim of the crater (Williams, 1942). Fine dust was undoubtedly dispersed for many hundreds of miles and probably encircled the globe. South and west of Crater Lake the pumice is confined largely to the valleys and canyons, having been deposited by glowing avalanches of pumice which flowed down the valleys for considerable distances. In the Rogue River canyon it flowed down valley for at least 15 miles, while to the northeast it flowed across Diamond Lake basin into the upper reaches of the North Umpqua River valley.

The deposition of the air-borne pumice must have had a devastating effect upon the forests in the region. The forests on the slopes of Mount Mazama were burned and buried by the pumice flows which were many tens of feet thick, as is shown by the abundance of charred logs. Beyond the limits of the pumice flows the pumice fall probably killed the trees, especially in the region of greatest depth, first by burying entirely the

seedlings and saplings, and then by the accumulative deleterious effects of the radically altered edaphic conditions. Aside from destroying the forests at the time of the eruption, the sterile pumice comprised largely of glass, has had a marked control upon the forest succession ever since. This vast pumice-covered area is today forested with species that have been able to persist only because of the absence of competition by species of the normal climatic climax.

There has been considerable postglacial volcanic activity in the Three Sisters region of the central Oregon Cascades also (Williams, 1944). Some of the mountains which were centers of this volcanic activity rose during the Pleistocene and have continued to be active in the Postglacial. Others are of postglacial origin and have erupted within the past several centuries. Most of these postglacial eruptions have been of the effusive type, resulting in lava flows of various kinds. A few volcanoes, including Tumalo Mountain and Devil's Hill, ejected pumice. Pumice from one or both of these sources either underlies or occurs as an interbedded layer in two organic sedimentary columns reported herein. Its stratigraphic position in relation to that of Mount Mazama indicates that these eruptions occurred after the climactic eruption of Mount Mazama. Another major postglacial eruption was that of Newberry Crater, located east of the main Cascade Range about 25 miles south-southeast of Bend (Williams, 1935). The dispersal of pumice from this volcano, like that of Mount Mazama, was also largely to the north and east. The stratigraphic position of Newberry pumice above that of Mount Mazama in postglacial sediments in the Summer Lake basin of south central Oregon indicates the relative times of these two eruptions (Allison, 1945). Newberry Crater pumice has not been noted in any peat sections so far.

Pleistocene mountain glaciation has left its record in the Oregon Cascades, although little work has been done on this problem. Thayer (1939) found three glacial stages which he named the Mill City, Detroit, and Tunnel Creek stages, and tentatively correlated with the Sherwin, Tahoe, and Tioga stages of the Sierra Nevada respectively (Blackwelder, 1931).

LOCATION AND CHARACTERISTICS OF THE BOGS.

This study is concerned primarily with the pollen analysis of sedimentary columns from five bogs located in the Oregon Cas-

cades. The interpreted forest succession, climate, and chronology, however, will be correlated with those from five other peat sections in the same region, that have been described in previous papers (Hansen, 1942, 1942a). These ten bogs are located in five different areas with respect to the occurrence and distribution of pumice. Two of the bogs of this study are located on the margins of Clear and Clackamas lakes respectively, in the northern Oregon Cascades, beyond the limits of discernible pumice from Mount Mazama. Clackamas Lake, the more southerly of the two, lies about 165 miles north of Crater Lake and about 70 miles north of the six-inch pumice zone in the vicinity of Bend (Fig. 2). Clear Lake is located about six miles north of Clackamas Lake. The thickness of the Clear Lake section is 2.4 meters and that of Clackamas Lake is 2.0 meters, although only 1.7 meters are pollen-bearing. Neither a layer of pumice nor scattered fragments of volcanic glass were noted in the sections. The elevation of Clear Lake is about 3,500 feet, while Clackamas Lake lies at an altitude of about 3,300 feet. The former is bordered by a sedge bog and the latter by a sphagnum bog with several typical bog plants present. Both bogs lie within areas covered by mountain glaciers and may be considered to have had a postglacial origin. They are located in the Canadian life zone (Bailey, 1936).

The two other bogs of this study lie on Mount Mazama pumice in tributary valleys of the Upper Rogue River southwest of Crater Lake (Fig. 1), where the pumice is largely confined to the valley floors. One is located on the floodplain of Lost Creek, a short tributary that empties into the Rogue River about ten miles west of Crater Lake. It will hereafter be referred to as the Rogue River section. The bog lies at an elevation of about 4,000 feet and is covered with sedges and sedge-like plants. The thickness of the sediments in the area of sampling is 4.0 meters. The pollen-bearing section is underlain with coarse pumice which grades upward into a fine, sandy pumice, and then into fibrous peat. The other bog in this area is located near Prospect, about 17 miles southwest of Crater Lake on the flood-plain of Red Blanket Creek which empties into the Middle Fork of the Rogue River. The peat deposit lies at an elevation of about 2,500 feet. The bog surface is covered with alder and willow due to lowering of the water

table by artificial drainage. The thickness of the sediments in the area of sampling is 3.2 meters, and examinations of the peat reveals that the bog has existed in the sedge stage throughout most of its existence. Both of the Rogue River bogs lie in the dryer part of the Humid Transition life zone.

A fifth section was obtained from a broad delta area at the south end of Diamond Lake where a short stream empties into the lake. The site of these sediments is located about 14 miles north of Crater Lake at an elevation of about 5,000 feet. The peat is only 0.5 meter thick and rests upon coarse pebble pumice, and the section contains a high fraction of fine pumice throughout. It is situated in the Canadian life zone.

Two of the other five bogs located in the Oregon Cascades and discussed in previous papers also rest directly upon Mount Mazama pumice. One of these is located in Munson Valley a few miles south and below the rim of Crater Lake, while the other is at Big Marsh about 30 miles due north of Crater Lake (Fig. 1). Two others are located on glacial drift or its chronological equivalent. One of these located near the Willamette Highway just west of the Cascade Drive and 50 miles north of Crater Lake is 2.75 meters deep with a layer of Mount Mazama pumice at 2.5 meters. The second has been formed at Tumalo Lake in a glaciated valley about 13 miles west of Bend. It is about seven meters deep and contains two interbedded strata of pumice. The lower layer at 4.5 meters is from Mount Mazama and the upper layer at 2.0 meters may be from Devil's Hill in the Three Sisters region, which was postglacially active (Williams, 1944). In a previous paper the author (Hansen, 1942) assigned the upper layer of pumice to Mount Mazama and the lower stratum to an unknown volcano. This was done because the upper layer is overlain by about the same thickness of peat as occurs in bogs that rest directly upon Mount Mazama pumice. A later comparison with Mount Mazama pumice revealed that it came from Mount Mazama (Allison, 1945). In yet another bog on the margin of Mud Lake, about 70 miles north of Crater Lake and west of Bend, the peat is underlain with a coarse pumice probably from a post-Mount Mazama eruption of Devil's Hill about five miles north of the site of the sediments (Hansen, 1942a).

With respect to age the bogs fall into three categories. Those at Clackamas, Clear, and Tumalo lakes and on Willa-

mette Pass are possibly the oldest because they rest on glacial drift or its chronological equivalent. Those lying on Mount Mazama pumice are younger because the eruption of this prehistoric mountain occurred after the maximum of the last Pleistocene glaciation (Williams, 1942). The Mud Lake bog is probably the youngest, as the pumice which underlies this section is of local origin and may be from the same source as the stratum at 2.0 meters in the Tumalo Lake profile. In the latter this layer is 2.5 meters above the Mount Mazama pumice stratum and must necessarily be considerably younger.

PRESENT CLIMATE AND VEGETATION.

The vegetation and climate of the Oregon Cascades vary considerably due to the great topographic relief and the influence of the mountain range itself upon the marine climate that spreads eastward from the Pacific Ocean. Although the air loses much of its moisture in traversing the Coast Range, on moving up the west slope of the Cascades it is again cooled so as to provide an annual precipitation of 90 inches in certain localities. Continuing to flow beyond and down the east slope of the Cascades the air is warmed dynamically and gives up little of its remaining moisture. Consequently the climate becomes more and more arid on the leeward slopes and out upon the Columbia Plateau and the northern Great Basin, where in some areas the annual rainfall is as low as ten inches. The continental influence becomes more pronounced eastward. In addition to the influence of the wide range in precipitation on the vegetation of the Oregon Cascades, the altitude and exposure also have a profound effect upon the forest composition due to variation in temperature.

On the west slope up to an elevation of 3,000 to 4,000 feet is the Humid Transition life zone (Bailey, 1936). Here the forests are luxuriant because of the comparatively warm climate and abundant rainfall. The principal arboreal species include Douglas fir (*Pseudotsuga taxifolia*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), lowland white fir (*Abies grandis*), noble fir (*A. nobilis*), incense cedar (*Libocedrus decurrens*), and sugar pine (*Pinus lambertiana*). The most common and widespread of these species are Douglas fir and western hemlock.

The Canadian life zone lies above the Humid Transition and with the exception of about a dozen of the highest peaks covers the crest of the Cascade Range. It extends down the east slope but not so far as on the west, because of the lesser precipitation and the warmer summers on that side. In the region of Crater Lake and for a distance of 60 miles to the north, the Canadian zone extends farther east than in the rest of the Cascades because of the greater altitude and precipitation. In the extreme southern part of Oregon the Canadian zone is very narrow and entirely absent in places, and the Humid Transition grades eastward directly into the Arid Transition with no intervening life zone. The principal forest trees in the Canadian life zone in the Oregon Cascades are western pine (*Pinus monticola*), lodgepole pine (*P. contorta*), Engelmann spruce (*Picea engelmanni*), western hemlock, Douglas fir, silver fir (*Abies amabilis*), and lowland white fir. In the southern part of the Oregon Cascades white fir (*Abies concolor*) and red fir (*A. magnifica*) are present, while in the northern half, western larch (*Larix occidentalis*) is not uncommon. Pollen analysis of the Tumalo Lake sedimentary column reveals that this species was more abundant in early postglacial time than at any time since (Hansen, 1942). The most abundant tree in the Canadian zone on the crest and east slope of the Cascades of central Oregon is lodgepole pine. It owes its great abundance to the pumice mantle that extends north and east from Crater Lake for a distance of 100 miles. The deposition of Mount Mazama pumice during postglacial time interrupted forest succession toward the climatic climax of the region, and has permitted lodgepole to thrive in the absence of competition of the other species that would normally forest the area under the existing climatic conditions (Hansen, 1942, 1942a). It has persisted since as an edaphic climax.

The Hudsonian life zone circumscribes the higher mountain peaks while some of the lower peaks are covered by this zone. It ranges from 5,000 up to 6,000 feet on the cold slopes in the northern part of the Cascades and from 7,000 up to 8,000 feet on the warmer slopes and in the southern part of the range. Forests are sparse and consist of alpine fir (*Abies lasiocarpa*), mountain hemlock (*Tsuga mertensiana*), whitebark pine (*Pinus albicaulis*), and Alaska cedar (*Chamaecyparis nootkatensis*). In the lower reaches of the Hudsonian zone within the pumice-

covered region, lodgepole pine is abundant. The highest peaks of the Oregon Cascades support the Arctic-alpine zone in which there are no forest trees.

The timbered Arid Transition zone covers the broad basal slopes of the Cascades and in the southern half continues for some distance out upon the plateau due to the higher altitude and greater precipitation. The most characteristic tree of this life area is western yellow pine (*Pinus ponderosa*). It is the most xerophytic of Pacific Northwest forest trees and is able to survive farther out upon the plateau and at lower elevations than other species. In the southern half of its range in the Oregon Cascades it forms patchwise stands with lodgepole pine, the latter, however, being much in the majority because of the thick pumice mantle. South and east of Crater Lake scattered stands of yellow pine occur due to differences in relief. It occupies the higher ridges and windward slopes wherever there is sufficient moisture. In the northern part of the Oregon Cascades, beyond the pumice mantle northward to the Columbia River, yellow pine forms a narrow and almost continuous zone due to the steep easterly slope and the absence of pumice. In this area lodgepole pine is confined largely to burns in the upper part of the Arid Transition and in the Canadian life zones. In the southern part of Oregon the range of yellow pine extends well west of the Cascades in the Rogue River valley and its tributaries. A few stands occur within 50 miles of the Pacific Ocean. Adjacent to the yellow pine forests on the east, western juniper (*Juniperus occidentalis*) occurs in sparse stands where soil and moisture conditions are favorable.

Postglacial Forest Succession.

Lodgepole Pine.

The general trends of forest succession as recorded in the Clear and Clackamas lakes sections are similar to those portrayed by pollen profiles in the Puget Lowland of western Washington where the bogs likewise overlie glacial drift (Hansen, 1941). In the lowest levels of both sections lodgepole pine is predominant, being recorded to 45 and 52 per cent in the Clear and Clackamas lakes sections respectively (Figs. 3, 4).

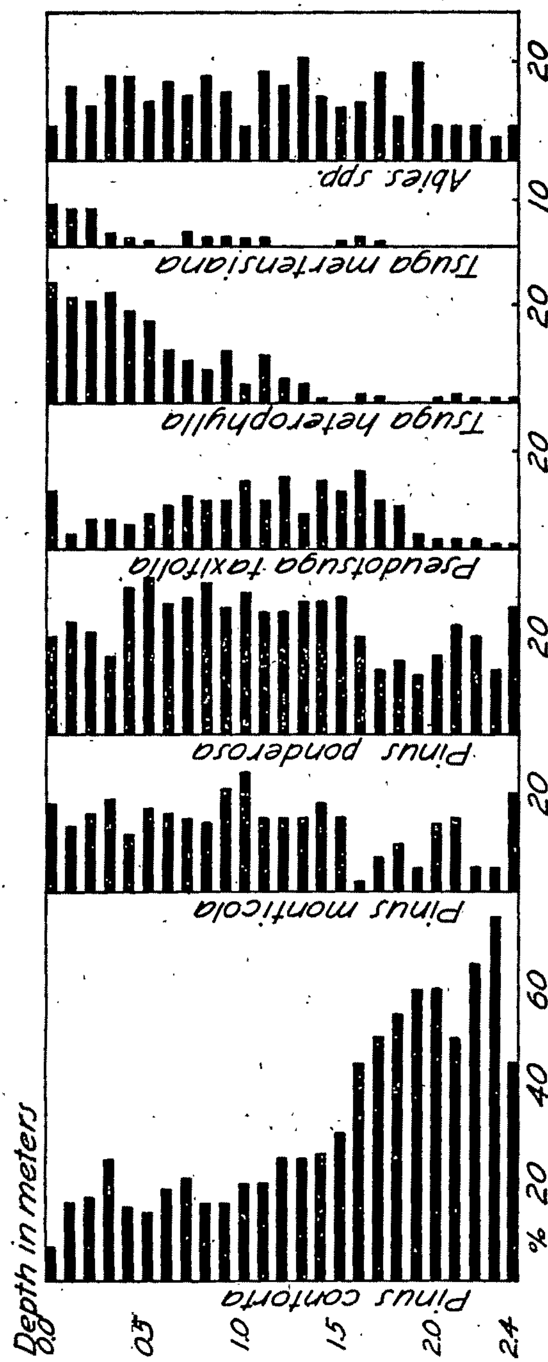


Fig. 8. Pollen diagram of Clear Lake sedimentary column.

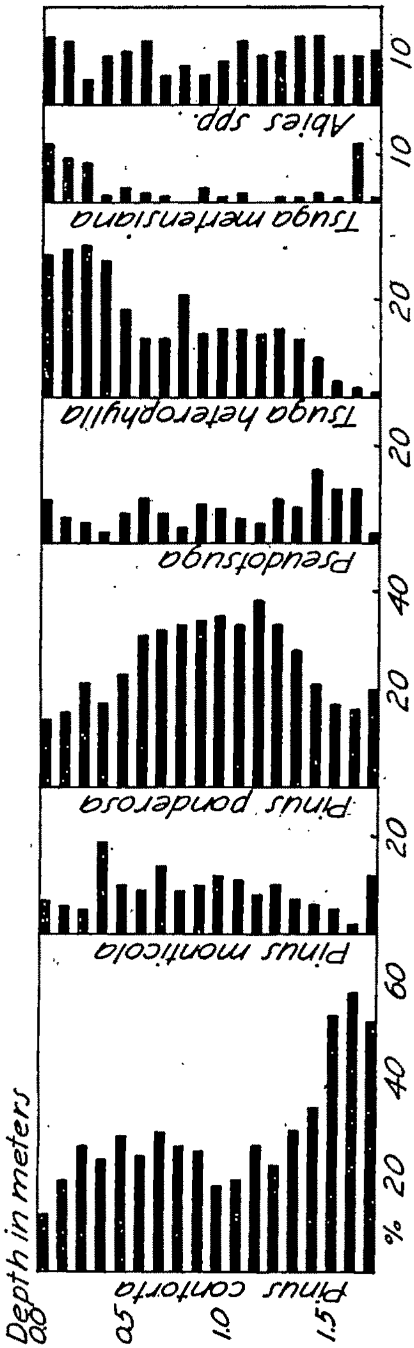
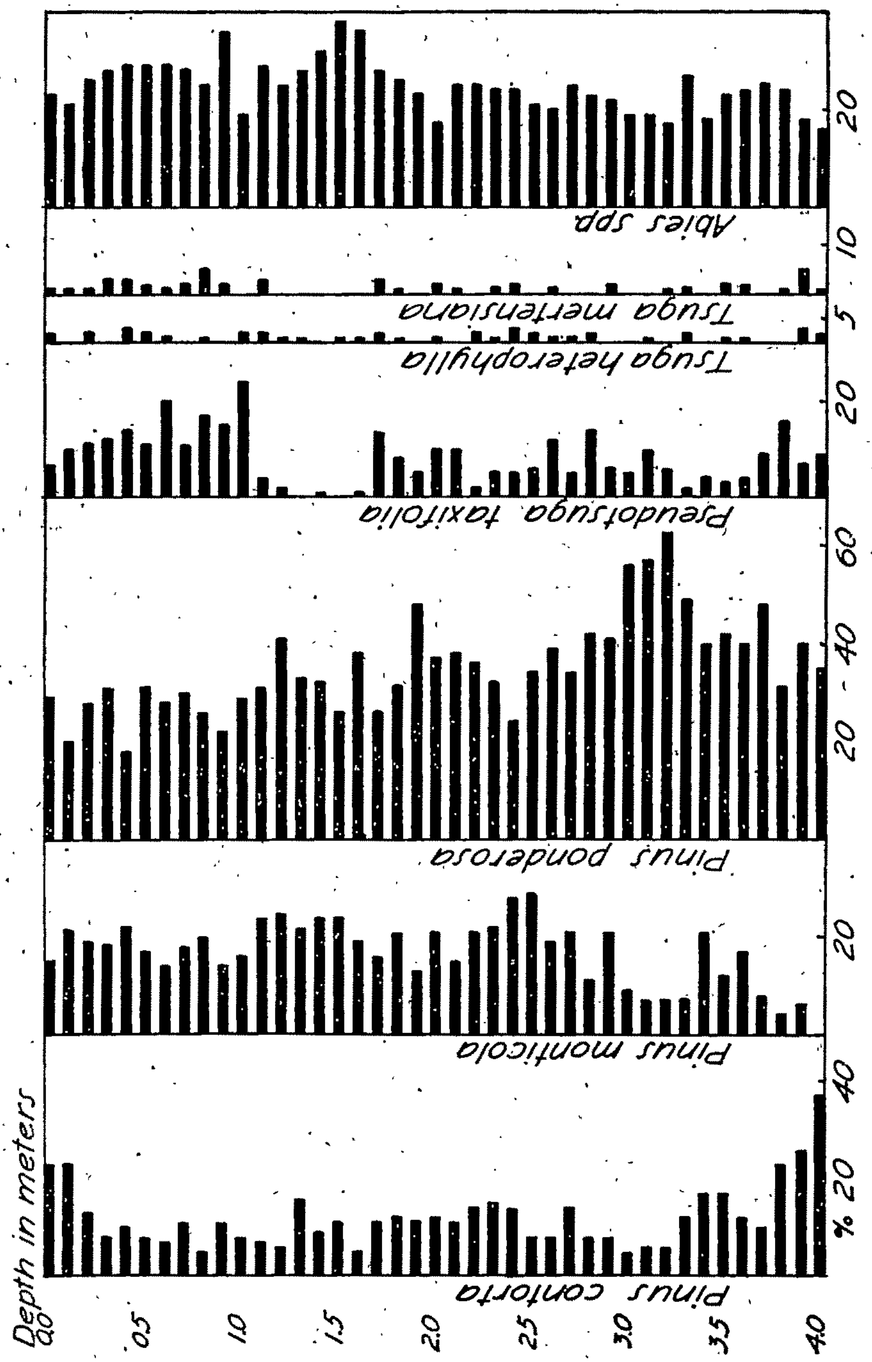


Fig. 4. Pollen diagram of Clackamas Lake sedimentary column.

In the level immediately above it increases to 75 and 58 per cent, which are its maximum proportions in the columns. This postglacial pioneer invasion of lodgepole pine on deglaciated terrain is characteristic over most of the Pacific Northwest. As the glaciers retreated the climate was still cool and moist and the edaphic and physiographic conditions unstable. Lodgepole, being an aggressive species, of prolific seeding habit, and producing seed at an early age, was able to persist close to the ice front. As the terrain was freed of ice, lodgepole was able to take advantage of the lack of competition and rapidly colonized the sterile mineral soil. Other species of greater longevity and with more tolerance for shade, however, replaced lodgepole as the soil was modified and the physiographic conditions became stabilized. The sharp increase in lodgepole immediately above the bottom is similar to that in most sedimentary columns in the Puget Lowland. Such an increase in so many profiles distributed over such a wide area suggests that the response was due to some systematic environmental change. It may reflect a slight readvance of the ice, causing unfavorable conditions for other species that had gained a substantial foothold and begun to replace lodgepole. From this maximum in the second lowest level of each section lodgepole generally declines upward and in both profiles reaches its lowest proportions at the top. An accelerated decline in the middle third of the profiles suggests a response to increased warming and drying which is so well depicted by many profiles throughout the Pacific Northwest. A slight expansion in the upper-third denotes a return to moister and cooler climate during the past several thousand years.

The forest succession as recorded in the Rogue River profiles is somewhat different from that revealed in the Clear and Clackamas lake sections. This is to be expected because the influence of Mount Mazama pumice was not felt as far north as these two lakes. Also the record is presumably older in these sections because they rest directly on glacial drift, while the Rogue River sections are underlain with Mount Mazama pumice. Local differences in climate, soil, and topography also have been contributing factors in causing different trends of forest succession. In the Rogue River sections lodgepole is slightly predominant in the lowest horizons, but its probable over-representation in pollen profiles suggests that western yellow pine was actually the most abundant arboreal species (Figs. 5, 6).


Abies spp.
Tsuga mertensiana
Tsuga heterophylla
Pseudotsuga taxifolia
Pinus ponderosa
Pinus monticola
Pinus contorta
Depth in meters
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
% 20
40
20
20
40
60
20
5
10
20

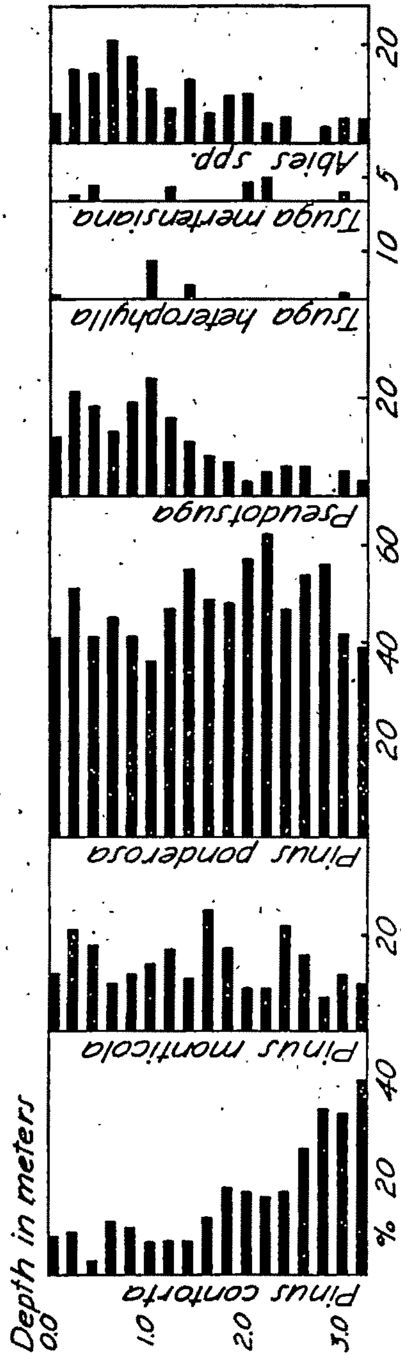


Fig. 6. Pollen diagram of the Prospect sedimentary column.

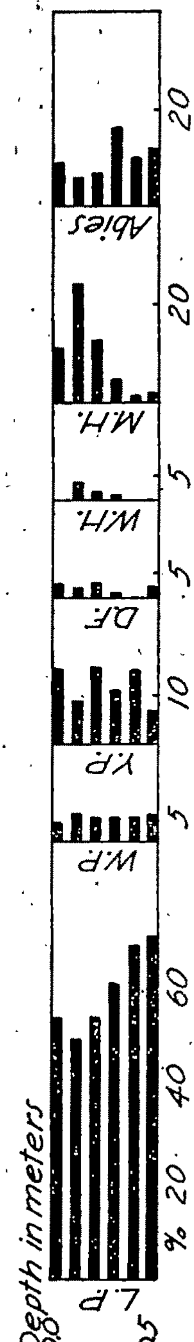


Fig. 7. Pollen diagram of the Diamond Lake sedimentary column, L. P., lodgepole pine; W. P., white pine; Y. P., yellow pine; D. F. Douglas fir; W. H., western hemlock; M. H. mountain hemlock.

In the Rogue River section lodgepole is recorded to 87 per cent, while yellow pine attains 35 per cent at the same level. In the Prospect profiles lodgepole is represented by 40 per cent and yellow pine by 39 per cent in the lowest horizon. At Diamond Lake, however, lodgepole is recorded to 71 per cent at the bottom and remains predominant throughout the sections (Fig. 7). This is to be expected because Diamond Lake is located in an area covered with five feet or more of pumice. In the upper Rogue River valley the pumice is confined to the valley floors so that forest succession on the ridges was not materially affected by the pumice. The maximum proportions of lodgepole at the lowest levels probably represent the remnants of a once more extensive postglacial forest of this species existing before Mount Mazama erupted and sedimentation began. In the Rogue River and Prospect sections lodgepole declines irregularly upward from the bottom. In the former a sharp increase at the top suggests the influence of recent fire which favored an expansion of lodgepole.

This record of lodgepole in all but the Diamond Lake section is quite different from that in the five other bogs previously studied. As revealed in the Tumalo Lake profiles early postglacial lodgepole pine forests were being replaced rapidly by yellow pine at the time of the Mount Mazama eruption (Hansen, 1942). The pumice fall, however, caused a sharp reversal of trends, favoring a rapid expansion of lodgepole. On Willamette Pass lodgepole also was favored by the pumice fall, while in the other three sections resting directly upon the pumice, lodgepole has been predominant to the present (Hansen, 1942a).

WESTERN WHITE PINE.

The pollen listed as white pine probably includes a fair proportion of whitebark pine pollen which drifted down from higher elevations. The profiles of these species reveal little that can be interpreted as a response to a systematic environmental change. In the Clear and Clackamas lake profiles an expansion in the upper third may reflect the cooling and humidifying of the climate during the past four thousand years as will be discussed later. In the Rogue River section a similar expansion of white pine in the upper two-thirds suggests the influence of a moister and cooler climate in more recent time. In the Prospect section, the white pine profile indicates little or

nothing in the way of a climatic trend. At Diamond Lake white pine is represented only sparsely throughout the section.

WESTERN YELLOW PINE.

The pollen profiles of western yellow pine from sedimentary columns located on the east slope of the Cascades, in the Columbia basin of both Oregon and Washington, and in the northern Great Basin of south central Oregon are good indicators of postglacial climatic cycles. The yellow pine forests of today lie between the timberless Arid Transition zone and the cooler and moister Canadian zone. The precipitation is and probably has been at a critical minimum so that slight increases or decreases have resulted in expansion or contraction of yellow pine forests, or downward or upward movements of the yellow pine zone on the east slope of the Cascades. In the Clear and Clackamas lakes sections, yellow pine is recorded to 26 and 20 per cent respectively in the lowest level (Figs. 3, 4). It declines for a few levels and then increases to attain its maxima of 32 to 38 per cent in the middle third of each profile. It generally declines again toward the top. The greatest proportions in the middle third of both profiles reflect postglacial warming and drying to its maximum degree. The total yellow pine proportions are low as compared with those in sedimentary columns located within or near the yellow pine zone of eastern Washington or the northern Great Basin of south central Oregon (Hansen, 1944, 1946). This is probably due to the proximity of the Canadian and Humid Transition life zones westward and windward from the sites of the bogs.

In the Rogue River sections yellow pine is more strongly represented due to the location of the bogs in yellow pine forests or forests containing a high proportion of this species. The bogs also lie at greater distance from mesophytic forests than do Clear and Clackamas lakes. The highest proportions of yellow pine occur in the lower half of each profile, thus reflecting the influence of the warm, dry period which reached its maximum after the eruption of Mount Mazama (Figs. 5, 6). As these sedimentary columns rest directly upon Mount Mazama pumice and are younger than the other two, the period of yellow pine maximum and predominance is contemporaneous in both sections.

In the Tumalo Lake bog yellow pine expanded rapidly in

response to early postglacial warming and drying but its expansion to predominance was interrupted by the pumice fall. Although the pumice mantle in this is only from six inches to a foot thick, it favored an influx of lodgepole to supersede yellow pine, which has persisted in predominance until today (Hansen, 1942). In those sediments lying directly upon Mount Mazama pumice yellow pine never was able to gain predominance (Hansen, 1942a). In four sections from Lower Klamath Lake yellow pine attained its maximum and predominance at a stratigraphic position that is consistent with other sedimentary columns in portraying the warm, dry stage which occurred after the eruption of Mount Mazama (Hansen, 1942b).

DOUGLAS FIR.

The pollen profiles of Douglas fir are not always indicative of climatic trends, because it has such a great geographic range and occurs in several formations with different phytosociological status in each. In the Clear lake profile its highest proportions are concurrent with those of yellow pine, suggesting that it responded in the same way to a drying climate. In the Rogue Valley sections the maximum proportions of Douglas fir in the upper third suggests its positive response to the cooler and moister climate of the past several thousand years.

WESTERN HEMLOCK.

The different interpretations placed on the maximum of Douglas fir in the two northernmost sections as compared with the two southern columns are supported by the profiles of western hemlock in the Clear and Clackamas lakes profiles. In this area Douglas fir and yellow pine evidently have been competing with western hemlock, mountain hemlock, and lodgepole pine. The limiting factor has been moisture but the precipitation is greater in this area than farther south. Also the influence of the Canadian and Humid Transition zones is more apparent because these zones are nearer the sites of the sediments. Furthermore, the prevailing winds from the west result in a stronger representation of forests of these two zones than of the yellow pine zone lying eastward and leeward from the sites of the sediments. In these moister zones Douglas fir competes with western hemlock, which in the absence of fire thrives better than Douglas fir. During dry periods Douglas fir is favored even

in the absence of fire. Hemlock was unable to take advantage of the moister conditions of early postglacial time because of the unstable and poor edaphic conditions which in the absence of competition by other species permitted lodgepole to predominate. As postglacial time passed the soil may have become modified but then the dry period hindered expansion of hemlock. During the last several thousand years, however, an increase in moisture has favored a marked expansion of hemlock, which attains its maximum at the top in both profiles. Mountain hemlock also reveals a similar trend but to a lesser degree. In the Rogue Valley profiles western and mountain hemlock are insufficiently represented to depict postglacial trends.

FIR.

The pollen profiles of the true firs do not portray any postglacial trend in the Clear and Clackamas lakes region. The species of fir pollen have not been separated, but in general most species require more moisture than yellow pine. In the Rogue Valley profiles fir is represented better than elsewhere and its trends are consistent with those of the other species. In general fir is more abundant in the upper half of the sections, indicating a positive response to cooler and moister conditions which have prevailed during the past several thousand years.

POSTGLACIAL CLIMATE AND CHRONOLOGY.

The climactic eruption of Mount Mazama resulting in the formation of the caldera holding Crater Lake occurred sometime after the maximum of the last Wisconsin glaciation (Williams, 1942). Williams estimates that the eruption took place between 4,000 and 7,000 years ago. Pleistocene glaciers advanced and retreated many times while Mount Mazama was rising. Ice tongues extended at least 10 miles from the summit and one extended 17 miles from the peak. In some canyons the ice was 1,000 feet thick and probably at times the entire mountain was covered with a system of glaciers. How much time passed between the time of maximum glaciation and the climactic eruption is hard to estimate, but according to Williams the glaciers had retreated until only three small tongues of ice extended beyond what is now the rim of Crater Lake. By comparing its remnant profiles with those of other cascade volcanoes formed of similar materials, the maximum height of

Mount Mazama is estimated by Williams to have been 12,000 feet. The forests on the slopes of Mount Mazama were scantier than they are today although they apparently consisted of the same species. Ring growth studies of charcoal logs buried by the pumice suggest that the local climate at the time of the eruption was similar to that of today (Williams, 1942).

The maximum of the last glaciation in the Puget Lowland of western Washington is dated at about 25,000 years (Antevs, 1945). This is correlated with the Mankato maximum of the last Wisconsin glaciation and with the Tioga glacial stage in the Sierra Nevada. Bogs resting upon glacial drift or its chronological equivalent are necessarily younger due to a lapse of time between deglaciation and the beginning of pollen-bearing sedimentation. The average age of 30 or more sedimentary columns resting upon glacial drift or materials of the same age in Washington, Oregon, and Idaho is estimated to be about 18,000 to 20,000 years. These figures are more or less arbitrary but they have been chosen upon several bases, including rate of ice retreat in other parts of North America, the depth and type of sediments, the climate in the several areas where the sediments have accumulated, the physiographic history of the region as well as that of the lake basin itself, the occurrence of volcanic strata in the sedimentary columns and their chronological correlation with one another, and the application of climatic and chronologic data from other sources to the pollen analytical data, chiefly the climatic stages as interpreted from the pollen profiles. Also the postglacial climatic trends and chronology as interpreted from pollen profiles in other parts of the world by many workers have served as a compromising factor.

Using Antevs' figures of 33 years per mile for the retreat of the Labrador ice from Long Island to the White Mountains (Antevs, 1922), from 5,000 to 7,000 years must have been required for the ice in the Puget Lowland to waste from its southernmost terminus to the Canadian border, a distance of about 200 miles. This leaves a figure of about 18,000 years since the present-day bog sites were freed of ice. Some may be older and some younger, depending upon the location of their sites with respect to the rate and method of glacial retreat and subsequent geomorphic changes. Mountain deglaciation probably lagged somewhat and so 15,000 years is estimated to be the

age of montane pollen-bearing sections that rest on glacial drift. In the state of Washington the occurrence of a volcanic ash stratum apparently from a single, contemporaneous source in most postglacial organic sedimentary columns correlated with the depth and types of sediments and the recorded plant succession provides an excellent common time marker and a chronological indicator. It is dated at about 6,000 years, or during the middle of a warm, dry postglacial stage. In Oregon the occurrence of one or more pumice strata in bogs in the Willamette Valley, the Cascades, and the northern Great Basin serves to segregate postglacial time into units which correlated with the forest succession and the climatic interpretation provides relative dates.

The Postglacial, which is here defined as the time since the last glacial maximum, has been divided into four climatic periods upon the basis of the pollen record from about 70 sedimentary columns well distributed throughout the Pacific Northwest. The first stage persisted until about 15,000 years ago and was cooler and moister than the present. Some of the sections may represent 5,000 to 10,000 years of this initial stage while others may have hardly begun before it ended. The second stage was one of warming and drying and lasted until about 8,000 years ago. During this stage, perhaps about 10,000 years ago, the temperature reached a level similar to that of today. The third stage, lasting from about 8,000 years ago to about 4,000 years ago, was one of maximum warmth and dryness, while the final stage of about the last 4,000 years has been cooler and moister.

A postglacial period of maximum warmth evidently was general throughout the north temperate zone, as is suggested by pollen profiles and peat stratigraphy from northern Europe, England, eastern North America, and the Great Lakes region (Blytt, 1881; Sernander, 1908, 1910; von Post, 1930, 1933; Godwin, 1940; Antevs, 1931, 1933; Sears, 1942, 1942a; Deevey, 1943, 1944; Potzger, 1942; Potzger and Richards, 1942; Wilson and Webster, 1942). The chronologic interpretations by these various workers for the duration of this thermal stage range from 6,500 to as low as 2,500 years.

Pollen profiles from 80 or more postglacial sedimentary columns in the Pacific Northwest that overlie glacial drift reveal consistent and definite evidence for a xerothermic stage

during postglacial time. This is best revealed in profiles from eastern Washington, the northern Great Basin of south central Oregon, and the Willamette Valley of western Oregon. It is less strongly pronounced in profiles from the Puget Lowland of western Washington and from northern Washington and Idaho.

The correlation of the time and duration of this warm, dry period with chronological data from other parts of the world, aids in constructing a time scale for the postglacial climatic sequence in the Pacific Northwest. The nearest links with European chronology are concerned with the fluctuations of the Great Basin lakes and the oscillations of western mountain glaciers. Antevs (1931, 1933) using summer temperatures for long distance correlation, dates the postglacial age of distinctly higher temperature in Sweden and Denmark from 6,000 to 2,000 B. C. He designates this age of warmth as the Middle Postglacial and uses it as a starting point in correlating the Swedish varved clay chronology (De Geer 1910, 1940) with North American postglacial climatic sequences. This chronology may be applied to the Pacific Northwest through the interpretations of the fluctuations of lake levels in the Great Basin. These lakes expanded and contracted in response to the Pleistocene glacial and interglacial stages. The highest stages of lakes Bonneville and Lahontan are correlated with the Iowan-Tahoe glacial stage, while the lower stages represented by the Provo shoreline in the Bonneville Basin and the Dendritic terrace in the Lahontan Basin are correlated with the Late Wisconsin (Mankato-Tioga) glacial stage (Antevs, 1941, 1945). In the Summer Lake basin of south central Oregon the highest levels of Pluvial (glacial) Lake Chewaucan are probably to be correlated with the Tahoe (Iowan or Early Wisconsin) glacial stage of the Sierra Nevada, and lower beach levels of Winter Lake with the weaker Tioga (Mankato or Late Wisconsin) stage (Allison, 1945). Continued fluctuations of Great Basin lakes during the Postglacial probably in response to climatic cycles is suggested by their present salinity. The present salinity of Owens Lake in California and Abert and Summer lakes in south central Oregon is such that it need not have required more than 4,000 years to have been reached (Van Winkle, 1914; Gale, 1915), indicating that they are not direct descendants of the Pleistocene lakes that occupied their basins.

The earlier lakes apparently dried up during the xerothermic interval of the Postglacial and their saline sediments were either buried or removed by deflation. Antevs (1945) dates this dry stage between 8,000 and 4,000 years ago. About 4,000 years ago an increase in moisture caused these lakes to be reborn and attain higher levels than at present. In Summer Lake basin an abandoned sandy beach ridge from 10 to 20 feet higher than modern Summer Lake suggests an expanded lake stage resulting from the increase in moisture a few thousand years ago (Allison, 1945).

Further support for the time and occurrence of the postglacial warm, dry stage is revealed by the history of modern glaciers in the western mountains. Modern cirque glaciers in the Sierra Nevada, most of the glaciers in the Rocky Mountains within the United States, and all of the lesser glaciers of the Cascade Range and Olympic Mountains probably represent a new generation of glaciers that came into existence in recent time, probably about 4,000 years ago (Matthes, 1939, 1942). The almost complete absence of ice in the mountains prior to this time denotes a long, warm interval.

Although the eruption of Mount Mazama took place after the maximum of the last Pleistocene mountain glaciation, the stratigraphic position of its pumice in sedimentary columns in the Oregon Cascades and northern Great Basin indicates that the volcanic activity occurred some time before the maximum of the warm, dry Middle Postglacial. In the Oregon Cascades western yellow pine had reached an advanced stage of expansion by the time of the eruption. This is indicated in sedimentary columns that rest directly upon Mount Mazama pumice as well as those that contain an interbedded stratum. Postglacial sections in the northern Great Basin reveal an interbedded stratum of Mount Mazama pumice above the maximum of yellow pine but below the maximum of grasses, Chenopods, and Composites (Hansen, 1946). This denotes that yellow pine expanded as the postglacial climate became warmer. Continued increase in temperature became unfavorable for yellow pine and favored an increase of grasses, Chenopods, and Composites, indicating that the eruption took place before the maximum of the drouth, but probably soon after the climate became somewhat similar to that of today.

The stratigraphic relationships of Mount Mazama pumice

and Newberry Crater pumice in the former bed of Lake Chewaucan and Winter Lake, pluvial antecedents of modern Summer Lake in south central Oregon, lend a clue as to the time of the Mount Mazama eruption (Allison, 1945). Pluvial Winter Lake, which is correlated with the Tioga (late Wisconsin) glacial stage, was still in existence several tens of feet above modern Summer Lake at the time of the major eruption. It must have persisted for some time afterwards because the Mount Mazama pumice is overlain by additional lake sediments including a layer of pumice from Newberry Crater. The final eruption of both volcanoes occurred before the culmination of the warm, dry interval in the northern Great Basin. Presumably the Pleistocene lakes dried up during the warm, dry Middle Postglacial, and Summer Lake was re-established in the lower part of the basin as the climate became moister in the last 4,000 years.

By correlating the Pleistocene and postglacial lake levels in the Summer Lake basin with those in the Lake Lahontan basin of Nevada, as interpreted by Antevs, Allison (1945) dates the eruption of Mount Mazama between 10,000 and 14,000 years ago.

On the contrary the thickness of the bog sediments overlying Mount Mazama pumice, the stratigraphic position of the interbedded pumice in relation to the warm, dry stages as interpreted from pollen profiles, and the correlation of many pollen profiles from the Pacific Northwest indicate to the writer that the eruption of Mount Mazama took place between 8,000 and 10,000 years ago.

The author is grateful to Dr. I. S. Allison, Oregon State College for reading the manuscript and for his criticism of the geological aspects.

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OBITUARY.

AMADEUS WILLIAM GRABAU.

An Appreciation.

The death of Amadeus William Grabau in Peking, China, March 20, 1946, removes one of the great geologists of the world. Although he had lived in China during the last 26 years of his life, he still had many friends in this country who will mourn him personally and many more who will be saddened by this loss to science.

Dr. Grabau's research work lay principally in the fields of stratigraphy, paleontology, and evolution. He published a 2-volume "Textbook of Geology," a large volume on "Principles of Stratigraphy," and collaborated in "North American Index Fossils" (2 volumes). He wrote many papers in pure paleontology, especially on mollusks and brachiopods, describing a very large number of new species and many new genera. His descriptions of these are full, carefully done and well illustrated.

He was closely associated with Alpheus Hyatt for eight years at the Boston Society of Natural History. Hyatt during these years was brilliantly applying the ontogenetic theory to the evolution of invertebrates. And Grabau's contributions to this line of research are outstanding. In gastropods, corals and crinoids, in brachiopods and cephalopods, he shows that the ontogeny of an individual repeats the phylogeny of the group to which it belongs, that the geological sequence of these ancestral forms is in the order indicated by the development of the individual.

During his later years Dr. Grabau was especially interested in the development of his Pulsation and Polar Control theories. According to the former the evolution of the crustal features of the earth is brought about by the rhythmic rise and fall of sea-level, expressed in its transgressions (pulsations) and regressions (interpulsations). All continents are thus affected at the same time. During regressions there occur erosion, continental sedimentation, mountain folding and vulcanism. With this Pulsation theory is linked the Polar Control theory. According to this there is a "periodic shifting of the earth's crust (sial-sphere) through the impetus given it by the rotation of the earth on an axis of essential constancy of position." In other words, the poles are constant in position but the sial crust is not. Thus the continents shift to the poles, accounting for glacial climates, and away from them, accounting for mild climates. As the

sial is partly submerged in the underlying sima, its movement produces mountains at its forward edge and fissures, with consequent vulcanism at its rear edge.

Dr. Grabau published four large volumes on the Paleozoic pulsations, but did not have time to complete his volumes on the Mesozoic and Cenozoic. However, in his "The Rhythm of the Ages," which appeared in 1940, he not only sums up his theory as applied to the Paleozoic, but also outlines his evidence for the succeeding eras.

Although many geologists will not accept these theories, they will remain an incentive to research, and the mass of data which he collected in their support is a storehouse of information upon which future workers will draw. HERVEY W. SHIMER.

SCIENTIFIC INTELLIGENCE

PHYSICS AND CHEMISTRY.

Physics and Experience; by BERTRAND RUSSELL. Pp. 26. Cambridge, at the University Press. New York, 1946 (The Macmillan Co., $.50).—This booklet is a reprint of the Henry Sidgwick Lecture, delivered at Newnham College, Cambridge, in 1945. In it, Russell gives his answer to the questions: "Assuming physics to be broadly speaking true, can we know it to be true, and, if the answer be in the affirmative, does this involve knowledge of other truths besides those of physics?". The answers are somewhat elaborate and involve an airing of the difficulties which often tend to make them uncertain. Among them is the circumstance that *perception* of physical facts is a mediate act, which may or may not bring the knower into exact contact with physical reality. Another is the *mental* character of perception as opposed to the *physical* character of the object. They are resolved by stipulating a causal relation between object and perception, and by defining a mental event in epistemological terms as one which we know "otherwise than by inference," so that "mental" is no longer opposed to "physical." Accepting these meanings, physics can be known to be true on the basis of purely physical knowledge. HENRY MARGENAU.

Synthetic Rubber from Alcohol; by ANSELM TALALAY and MICHAEL MAGAT. Pp. xiii, 298; 64 figs. and many Tables. New York, 1945 (Interscience Pub. Co., $5.00).—This book is made up of four long chapters which treat the chemistry of the Lebedev process, the technological aspects of the process, the polymerization of the butadiene product, and the physico-chemical properties of the resulting polymer.

The first chapter contains an abundance of information on the products of alcohol dehydration and dehydrogenation and the mechanisms by which they originate. It is very lacking, however, in specific information about the nature of the catalysts which promote the reaction. The second chapter is informative but largely based on old work (1936 and before) done at a time when, in the author's words, "the chemical apparatus industry in the U.S.S.R. was very much in its infancy." The treatment of analytical methods, safety hazards and other such matters is helpful. The chapter on polymerization is good, that part pertaining to emulsion polymerization especially so. The discussion of the properties of the polymer is

more directed toward the physical chemist than the rubber technologist.

The book is well-arranged; the figures are good. The subject index is not as complete as could be desired. HARDING BLISS.

The Chemical Process Industries; by R. NORRIS SHREVE. Pp. xiii, 875; many illustrations. New York and London, 1945 (McGraw Hill Book Co., $7.50).—This book begins with an excellent statement of objectives and fundamentals with which the ensuing study of the chemical industry is approached. The importance of cost and the general problems common to all branches of the industry are suitably emphasized. Each of the remaining thirty-four of the thirty-nine chapters is devoted to one particular branch of chemical manufacture. No important branch is omitted. The book is well-illustrated and has a good index. The author's choice of references for supplementary reading is to be commended.

As a relatively concise and complete review of the essentially qualitative aspects of chemical industry this book is probably without equal. HARDING BLISS.

Principles of Industrial Process Control; by DONALD P. ECKMAN. Pp. x, 237; 175 figs. New York and London, 1945 (John Wiley and Sons, $3.50).—This is an excellent book and one which fills a very great need. The current periodical literature on instrumentation is so highly specialized in content and so much obscured by unusual terminology that the reader seeking a broad view is more likely to be confused than enlightened. This book will be of great benefit in this connection. It describes clearly the fundamentals of measurement and control. The first three chapters deal with means of measurement of the several process variables and their characteristics. The next two chapters are concerned with the means of adjustment of supply according to the demands of the system. An excellent chapter on the character of the process under control and the inherent "lags" is included. The remaining chapters cover the theory of automatic control, the quality of control, applications, control systems, and maintenance.

The index is adequate. A seven page glossary of terms will be most useful to the general reader.

The book is heartily recommended to any engineer in the process industries. HARDING BLISS.

Atomic and Free Radical Reactions. The Kinetics of Gas Phase Reactions Involving Atoms and Organic Radicals; by E. W. R. STEACIE. American Chemical Society Monograph Series, No. 102. Pp. vii, 547. New York, 1946 (Reinhold Pub. Corp., $8.00).—One of the most difficult branches of chemistry concerns itself with the

interpretation of data on rates of chemical reactions. Of fundamental importance both for theoretical and for practical reasons the problems involved are not easily brought to satisfactory conclusions. The experimental work is difficult to make exact; detailed theoretical guides of a practical nature are largely lacking. The literature of chemical kinetics is immense. Particularly in the field of gas reactions—where there is more chance of obtaining theoretically interpretable results—has a great amount of work been done. The trend of results has been to show that chemical reactions, however complex, are usually the overall result of a series of simple elementary reactions. The present book is a comprehensive review of the work on a large class of elementary gas phase reactions, those involving more or less short-lived chemical fragments.

After a very short introduction in which are briefly summarized some of the results of the theory of kinetics the author proceeds at once to his chief business. Chapters II to V, the first half of the book give a general discussion of "experimental methods and of the rôle of atoms and radicals in thermal and photochemical reactions." In the last half of the book "an attempt is made to discuss all data which have a bearing on the rates of individual elementary reactions." This attempt may possibly not have been one hundred per cent successful, significant data being frequently buried in most unlikely and as well as inaccessible spots, but the author has certainly accomplished a monumental task. The survey will prove most useful for anyone working with gas reactions. As a source of suggestions for research the book will be well-nigh inexhaustible. The author has been forced to make other than definite statements about the mechanisms of very many of the reactions he discusses. Indeed, a second sub-title of the book might well read: *A Left-handed Account of the Unsatisfactory State of Chemical Kinetics.*

The utility of the book is enhanced by the reaction index, which enables one to find readily any reaction discussed. There is in addition a subject index. The book manufacture is up to the usual high standard of the Monograph series. HENRY C. THOMAS.

Modern Chemistry. Some Sketches of its Historical Development; by A. J. BERRY. Pp. x, 240. New York, 1946 (The Macmillan Co., $2.50). (Cambridge University Press).—Nine independent essays on the development of various branches of chemistry make up this book. The chapter headings summarize its contents: I, Classical Atomic Theory; II, Electrochemistry; III, Stereochemistry; IV, Radioactivity; V, Elements, Isotopes and Atomic Numbers; VI, Some Experimental Studies on Gases; VII, Some Problems of Solutions; VIII, Some Essential Features of Chemical Change; IX, A Retrospect. Chapter VIII concerns itself largely with the

history of chemical kinetics. Chapter IX is a discussion of the history of the relation of chemistry to other sciences, in particular, to physics and to biology.

Any chemist could improve his perspective of the science by a careful reading of these essays. The book should be especially recommended to seniors and graduate students preparing for comprehensive examinations in chemistry. HENRY C. THOMAS.

Colloid Chemistry, Theoretical and Applied. Volume VI. Edited by JEROME ALEXANDER. Pp. vii, 1215; New York, 1946 (Reinhold Publishing Corp., $20.00).—This volume, like its predecessors, contains articles on a very wide variety of subjects. The topics covered range from physical instruments such as the mass spectrometer and the Geiger-Muller X-ray spectrometer to purely technological matters such as the fluids used in drilling oil wells. The volume is divided into two parts, the first of which contains thirty-eight papers on "General Principles and Specific Industries," while the second is composed of thirty-two articles in the field of "Synthetic Polymers and Plastics." Most of the articles contain extensive bibliographies. A very competent group of authors has been assembled by the editor.

The only method by which the extent of this volume could be shown would be to list the table of contents. Space limitations preclude this. However, it is safe to say that any industrial chemist will find material here which is pertinent to his own industry. Academic scientists will be interested in the above-mentioned articles on the mass and X-ray spectrometers, in Harkins' paper on surface films on solids and liquids, in Zworykin's and Hillier's discussion of some of the practical aspects of electron microscopy, in Emmett's treatment of catalysis and its industrial applications, and in many of the other articles. The papers in Part II cover practically all the commercially important synthetic plastics. They are written, for the most part, from the technological point of view, and thus contain much information of rather wide interest which it would be difficult to find elsewhere.

The book maintains the high standards of format established by the other volumes of this series. In particular, mention may be made of the numerous and helpful figures and of the rather complete indexes. The latter are very useful in a book containing such a diversity of subjects. JULIAN M. STURTEVANT.

PALEONTOLOGY.

Apes, Giants and Man; by FRANZ WEIDENREICH, Univ. of Chicago Press, 1946. Pp. 1-122, 90 text figures, $2.50.—This book is the printing, somewhat augmented, of five lectures delivered at the Uni-

versity of California in the spring of 1945. The lectures, each of which is more or less independent of the others, set forth the author's conclusions concerning man's evolution as it appears from the records of the past.

Man's place in the zoological scale is clearly established with the three existing great apes as his nearest of kin. The likenesses are so great that the author stresses the points of difference rather than evidences of kinship. These are largely the early assumption on the part of humanity of the erect posture permitting him to use his feet solely for locomotion and freeing the hands for other use. This has reacted on the construction of the feet and vertebral column and on the form of the skull as well. Limb proportions have also changed, especially the relative lengths of upper arm and thigh.

The number of teeth is alike in ape and man, but the latter lacks the projecting, fang-like character of the canine teeth and only in the most primitive forms is there any gap in the tooth row. The form of the dental arch, nearly parallel sided in the ape, is a widely expanded curve in man. The projecting muzzle and heavier face of the ape are correlated with a smaller brain case—in man the reverse is true and the brain case lacks the crests and buttresses which in the gorilla not only serve to strenghen the skull against muscular strains but provide space for the attachment of the powerful muscles of the jaws. Man, as known from the fossil record, is divided into three sub-families which merge into and succeed each other in time. There are the Archanthropinae including such well-known forms as *Pithecanthropus, Sinanthropus,* and the recently discovered giant species, *Gigantopithecus* from China, and *Meganthropus* from Java. Not only is great size indicated by the very fragmentary remains of the last two, but, in common with the others, a marked robustness of bone which leads the author to believe that giantism was a characteristic of our remote ancestry and reduction of stature and of bone thickness were part of the evolutionary trend.

The Paleoanthropinae include the Rhodesian man, Neanderthal man, and the Palestinian men from Mount Carmel which show traits of the Neanderthals together with those of our own species, *Homo sapiens,* possibly from hybridizing although Weidenreich seems to think that some of the Mount Carmel men at least were actually transitional into *sapiens.*

Modern men such as those of Cro-Magnon together with all existing humanity are grouped as Neanthropinae. The change of form of the cranium together with the progressive lightening of the bones are from a low-crowned skull, relatively large of face and with heavy brow-ridges and small brain capacity to the condition seen in modern man. Neanderthal man, while showing many of the more primitive traits, had, nevertheless, a cranial capacity exceeding that

of the average European of today, which shows that increase in brain volume has not progressed for the last 10,000 to 20,000 years! But the form of the cranial cavity has changed, especially in the parietal region, which allows for a greater development of the parieto-temporal portion of the brain without an increase in total volume. And the brain has changed in yet another way, through the increase of the area of its cortex which could only be brought about by a deepening and further elaboration of the infolded area, a process of which the endocranial impression gives very little clue. For as the author says: "if a special type of mentality were really to depend on the form of the brain, this could never be recognized by the shape of the bones which cover it," and that is all that the student of fossil man possesses.

Weidenreich's exposition of the evidence at his disposal is clear and his conclusions are apparently well founded. His opportunities to study the material directly have been ample and he speaks with high authority.

RICHARD S. LULL.

Miscellaneous Scientific Intelligence.

English-French and French-English Technical Dictionary; by Francis Cusset. Chem. Publ. Co., Brooklyn, N. Y. 1946. Price $5.00.—This dictionary contains approximately 16,000 words and phrases. It covers adequately the fields of metallurgy, mining, chemistry, electrical engineering and physics, in that order of thoroughness. French equivalents of English expressions, and vice versa, are chosen with competence and accuracy. The book is highly recommended to all workers in natural science, to librarians and translators. It seems surprisingly up-to-date in most aspects of applied science, although some terms having reference to recent developments in atomic physics are missing.

HENRY MARGENAU.

Luther Burbank. A Victim of Hero Worship; by W. L. Howard. Vol. 9, No. 5/6, Pp. 299-522; 6 figs., 7 plates. Waltham, Mass., 1946 (The Chronica Botanica Co. $3.75), New York City (G. E. Stechert & Co.).—The personality and accomplishments of Luther Burbank were the subject of much controversy during his lifetime and immediately after his death in 1926. Even now, some twenty years later, interest in his career has not lapsed, as is witnessed by the appearance of another recent biography (in addition to the present one) and the issuance by the United States Post Office Department in 1940 of a commemorative Burbank Stamp. In writing the present volume the author states that he has given up the

hope of bridging the chasm between the extreme admirers of Burbank and those who deprecate him, and rather has directed this work to the "host of people who have no violent feelings about Burbank one way or the other and who merely want the honest facts about the man and his life work, his value to human society as a whole, not alone to the science of plant breeding." The present reviewer feels that the author has succeeded very well in his task of presenting an objective evaluation of his subject's career. From it emerges the picture of a man who was an able, energetic, fundamentally honest, practical plant breeder, most of whose alleged extreme virtues or faults were due largely to his exploitation by unscrupulous associates. The present volume does little, however, to enhance Burbank's reputation as a scientist. Despite the undoubted practical value of many of his productions (of which a useful summary is presented in Chap. 19), it still seems apparent that Burbank made little or no real contribution to advancing the science of plant genetics. NORMAN H. GILES, JR.

PUBLICATIONS RECENTLY RECEIVED.

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Illinois Geological Survey. Geologic Map of Illinois; compiled by J. M. Weller with collaboration of L. E. Workman, G. H. Cady, A. H. Bell, J. E. Marmar, and G. E. Eckblaw. Urbana, 1945.

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VOLCANIC HEAT

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ABSTRACT. It is difficult to reach any definite conclusion regarding the origin of volcanic heat, mainly because of the conflicting character of the evidence. When two conflicting observations of equal weight are presented, the writer's position is to assume that both are probably correct. E.g., he assumes that there may exist magmas with a very small water content and others consisting almost entirely of water of very deep origin. It is suggested in the same manner that magmas may be formed at various levels in the mantle and in the crust, and a theory of "statistical" melting is presented as a new line of investigation. Magmas are believed to have several "parents," one of which may be diffusion of water and less common metallic constituents from the core of the earth. Volcanic activity, a rather insignificant phenomenon, results probably from the simultaneous operation of a number of factors.

INTRODUCTION.

PROFESSOR GRATON (4) has made recently on the subject of volcanic heat a substantial contribution which is, however, of a decidedly negative character. It is undoubtedly very important to know what does not happen in a volcano, and in this respect Dr. Graton's statements concerning chemical reactions as a source of heat are important. But the present writer, who has spent much of his time in the last eight years in an environment of active volcanoes, and very active ones at that, feels that the subject might perhaps deserve a more constructive treatment. Let it be clear at once to the reader that the object of this paper is not to suggest a definite solution to the problem of volcanic heat; the picture of volcanic action detailed in § 28 is given mainly to call attention to several possible lines of investigation which might provide a better approach to the subject.

2. It is very remarkable and disappointing indeed that the wealth of information on volcanoes that has been gathered in the past 50 years does not seem to have added very much to our knowledge of the ultimate causes of volcanic

activity. The reason for this may be that most attempts at generalizations fail because of the contradictory and sometimes apparently irreconcilable character of the evidence. Examples of such conflicting data will be given below. It is important to remark that much of this evidence, contradictory as it may seem, cannot be discarded lightly on the basis that it appears fantastic. If Perret, having observed the 1906 eruption of Vesuvius at closer quarters than any one else, feels that more gases were driven off than lava, there is a strong case for the point, difficult as it may be to reconcile this observation with our present, limited knowledge of magmas. Even if Graton proves in an apparently successful manner that exothermic reactions fail as a possible source of volcanic heat, must we forget that a 30 years' experience at active volcanoes convinced Jaggar (6) to the contrary?

3. The present writer's position is to assume, in the face of conflicting evidence, that both propositions are presumably true, the contradictions arising probably from our inability to see the exact relations. This inability may result from incorrect or incomplete statements, or from the fact that we are neglecting some factors. There may also possibly be only a statistical truth, with real deviations. Two observers drawing a small number of samples of black and white balls may reach different conclusions as to the proportion of white balls to black ones in the box. They are both right, on the basis of their observations; the only trouble is that these observations are incomplete.

4. To see more clearly how this could happen in the present case let us consider volcanic phenomena in their true proportion as compared to the earth as a whole.

As regards volume: An accumulation of lava of the plateau type may be of the order of 10^{21} cm^3 (one million square kilometers, one kilometer thick). Suppose 30 such outpourings to have occurred since the beginning of the Cambrian period, and the writer confesses he could probably mention no more than 10 or 12 such occurrences. The total volume of lava erupted since that time (3×10^{22} cm^3), compared to the total volume of the crust down to a depth of 70 km. (3.56×10^{25} cm^3) amounts only to one part in a thousand. The outpouring of these plateau masses may have lasted many million years, so that the volume of the crust that was actually molten at any

time must have been much less still. A present day "large" eruption, would amount to something around 10^{15} cm^3 on the average; this is only 10^{-10} times the volume of the crust.

As regards heat: Take the total heat lost by one gram of lava crystallizing and cooling from 1000°C to ordinary temperature to be 400 calories (300 cal. from specific heat, 100 cal. from latent heat). Then the total amount of heat required to account for all volcanic activity since the close of the Precambrian would be of the order of 4×10^{25} cal. The heat conducted to the surface and lost by radiation in the same time would be, taking an average of 1.10^{-6} cal/cm^2-sec, 5.08×10^{18} cm^2 $\times$ 15×10^{15} sec $\times$ 1.10^{-6} cal/cm^2.sec or 7.5×10^{28} cal in all. Volcanic heat represents only a very small fraction of the heat radiated by the earth.[1]

These facts suggest that the real problem of volcanoes is not so much to find a suitable source of energy as to provide ways and means by which rather insignificant amounts of heat can be focussed on relatively insignificant volumes of the crust. The orders of magnitude suggest that volcanic activity may result from a coincidence of various factors which may themselves have a small probability by usual standards. In other words, volcanic activity may be something exceptional, and there may be no need to wonder if its manifestations occasionally show somewhat unexpected deviations from the behavior that purely petrological thinking has accustomed us to consider as normal.

Following Graton's treatment of the subject, we shall take up successively the following points: 1) cooling by expanding gases, 2) gas/lava ratio, 3) chemical heat, 4) internal heat. We shall then proceed to suggest two lines of investigations that might provide useful results.

COOLING BY GAS EXPANSIONS.

5. To those who contend that rising gases may act as a heating agent, Graton opposes the statement that gas is a powerful refrigerant. Since it has appeared, mainly

[1] Heat losses represented by intrusion and metamorphism need not be considered, as they will automatically reappear in the radiated heat. The adopted value for radiation (1.10^{-6} cal cm^{-2} sec^{-1}) applies presumably only to a portion of the crust which has not recently suffered igneous activity.

through work by Jaggar and others at Kilauea, that there does seem to be a heating effect connected with the gas discharge, it may be useful to find out just what Graton means. His argument, based on thermodynamical calculations, is to the effect that a granitic magma containing 9.4% of water at 1200°C and 10,600 bars would cool, as a result of its expansion to atmospheric pressure, by 356°, the various causes of cooling being computed as follows:

Expansion of melt	11° 69
exsolution of gases	30° 28
expansion of gases	314° 78
	356° 75

And Graton adds that this amount "must be increased by conductional, kinetic, and surface losses not here evaluated" (ref. 8, p. 221).

6. Let us consider mainly the cooling by expansion of gases. Graton has computed this factor from the adiabatic expansion law for a perfect gas, but he writes (p. 217): "the adiabatic fall in temperature of the gas, translated into calories, is redistributed to the gas and melt, in accordance with the weight per cent of the two phases." Now this means that the gas is supposed to cool the melt, i. e., to receive heat from it. Hence the expansion is not adiabatic in the first place. Furthermore, if the kinetic energy is disregarded as well as the conductional and radiation losses and the change in potential energy required to lift the magma to the surface, then it is clear that the rising magma 1) loses no heat, 2) performs no mechanical work and therefore expands at constant internal energy. For a perfect gas expanding at constant internal energy, there is no cooling at all.

On the other hand, if the kinetic energy is considered as indeed it should, then the pressure distribution in the conduit must be different from that assumed by Graton on the basis of hydrostatic equilibrium, because if hydrostatic equilibrium prevailed, there would be no movement and hence no kinetic energy involved in the expansion.

7. The actual cooling resulting from the expansion, taking kinetic energy into account, may be computed as follows.

If a fluid expands from a pressure p_0 to a pressure p_1, the change in velocity is given by the familiar relation

$$\frac{c_1^2-c_0^2}{g}=-\int_{p_0}^{p_1} v\,dp \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Put $C_0=0$ and suppose the expansion occurs adiabatically. Then pv^{γ} is constant and

$$\frac{c^2}{g}=p_0 v_0 \frac{\gamma}{\gamma-1}\left[1-\left(\frac{p}{p_0}\right)^{\frac{\gamma-1}{\gamma}}\right] \quad \ldots\ldots\ldots (2)$$

Let us find the pressure ratio $\frac{\rho c}{\rho_0}$ corresponding to a maximum discharge c/v per unit cross section. Putting $\delta\left(\frac{c}{v}\right)/\delta\left(\frac{p}{P_0}\right)=0$ in equation (2), we find

$$\frac{p_c}{p_0}=\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$$

and the corresponding velocity C_c is such that

$\frac{c_0^2}{g}=p_0 v_0\frac{\gamma}{\gamma+1}$. This is the velocity corresponding to the maximum discharge that can be obtained, whatever the pressure ratio P_0/p.

Assuming a perfect gas

$$\frac{c_0^2}{g}=\frac{\gamma}{\gamma+1}\frac{RT_0}{M} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

where M is the molecular weight. Put $M=18$ and $T_0=1200°C$, $\gamma=1.3$. Then $\frac{C_c^2}{g}=0.38\ 10^{10}$, or $C_c=870$ meters per second.

The kinetic energy involved in the expansion of 9.4 grams of water is then

$$9.4\times 0.38\ 10^{10}\ \text{cgs}=850\ \text{cal.}$$

If this heat could be subtracted somehow from the 90.6 remaining grams of melt, with an assumed specific heat of 0.3 cal/gr. 1°, the cooling would be $\frac{850}{90.6\times 0.3}=31°$ instead of

814° as computed by Graton. Furthermore, the cooling of the gases would probably occur at a time when there would be little opportunity left for heat exchange between these gases and the melt, and the expansion might thus have no thermal effect on the melt at all.

Thus, although the writer agrees that a certain amount of cooling may occur under certain circumstances, he sees no reason to assume 1) that cooling takes place necessarily, 2) that it amounts to several hundred degrees, 3) that these same gases which may cool as they rise have not exerted previously some heating influence connected possibly with the formation of the magma itself.

GAS/LAVA RATIO.

8. A critical examination of the data leads Graton to conclude that Alfano and Friedländer's computations concerning the weight of gas discharged during the gas phase of the 1906 eruption of Vesuvius must be incorrect; in his opinion the eruption of more gases than lava (in weight) amounts to an impossibility. The present writer is willing to concede that this is the fact concerning Vesuvius because he has no direct knowledge of the case, but would Graton's statement apply to any volcano or to any magma? To be sure, the author hopes to have demonstrated that in the 1938 eruption of Nyamlagira the total amount of gases discharged was only a very small fraction of the weight of lava (15); and the same may be true of the 1929 eruption of Vesuvius. But the writer has also witnessed for several years the activity of Nyragongo, next neighbor to Nyamlagira in the Virunga group. The visible activity at this volcano consists entirely and solely in the permanent occurrence of glowing lava pools within the crater, and the discharge of a large volume of gases and vapor. Observations are difficult because this vapor usually fills the crater; yet the glow of the overhanging clouds at night, which has been observed continuously for over ten years, leaves no doubt as to the permanent discharge of volatile matter and radiated heat. Since no lava is discharged outside the crater and no notable change in the level of the lava within this crater, the ratio gas/lava must be infinite. It is true that much of the gases may be meteoric water, but water vapor does not have the characteristic brown-blue color of the Nyragongo

gases, which must therefore be partly of magmatic origin. It would appear thus that at some volcanoes and at some times the amount of gases discharged may be considerably greater than the amount of lava. This would seem to conflict with Graton's conclusions.

The same contradictory behavior may be observed in intrusive magmas. Sills, even when intruded quite near the surface, are commonly surprisingly non-vesicular. Many granitic masses have been intruded at such shallow depths that it is almost certain, on the basis of Goranson's data, that if they contained a notable proportion of volatile constituents, they would have blown off their roof. If such were the case, we would expect to find quite frequently, associated with granitic masses: 1) pyroclastic deposits, 2) rhyolitic extrusives or a chilled upper zone. Such occurrences are, to the writer's knowledge, quite rare, and he concludes therefrom that the amount of volatiles in the magma must have been small, say one percent or less. On the other hand, certain magmas surely contain very large quantities of water.

9. There are several distinct lines of evidence to this effect. One of these is the intensity of pyrometasomatic processes in the neighborhood of some intrusions. Another line of evidence relates to what we know of the solubility of certain minerals found in deposits of magmatic affiliation. Take the various copper sulphides for instance. Their solubility, even at 400°C, is apparently very small, of the order of 10^{-10} gram of copper per liter (3, 14). Consider now a medium-size copper deposit containing, say, 100,000 tons of copper. The amount of water required to dissolve all this copper is of the order of 10^{21} liters, or 10^{24} cm.^{3} Taking the density of water vapor at its critical point as 0.3, the corresponding weight is 3×10^{23} grams, or about one tenth of the total mass of the oceans. The mass of the original magma would be, assuming a water content of 1%, 3×10^{25} grams, or one half percent of the total mass of the earth. Surely copper sulphide must have been transported in a more soluble form. But there is another line of evidence that leads to figures of a similar order of magnitude. Douglas (1) has shown that the structure of some vein deposits indicates deposition under condition of turbulent flow. This gives an idea of the velocity of mineralizing solutions as a function of the width of the vein; it would be, according to Douglas, about

$\frac{1}{2}$ cm. per second for a vein 10 cm. wide. Take such a vein, 10 meters in length. The section of this vein is 10^4 cm^2 and the discharge 5×10^8 cm.^{3}/sec. Now Douglas believes that the filling of certain veins may have required several million years; this is also about the time required by a large-size batholith under a cover 5 km. thick to cool through the range of temperature corresponding to hydrothermal deposition (9). Then the total volume of solution flowing through the vein is of the order of 5×10^8cm^3/sec $\times$ 3 10^{13} sec$=1.5 \times 10^{17}$cm^3, or 4.5×10^{16} grams. If there are only 100 such small veins connected with a batholith containing initially 1% of water, the volume of this batholith must have been 1.65×10^{20} cm^3 (say 165 km. long, 100 km. wide, and 10 km. thick).

10. The implication seems to be that certain magmas contain a much higher proportion of water than 1%. The actual figure might be closer to 100% than to 1%, indicating that some "magmas" probably consist entirely of water and other volatiles, with small amounts of solute. In other words, there may possibly exist in the crust large masses of fluids, impregnating, adsorbed on, and diffusing through, the crust, independently of any silicate melt. The igneous intrusions associated with certain mineral deposits are not necessarily the origin of these deposits, they might be in some cases simply a by-product of the process through which these deposits were formed.

CHEMICAL REACTIONS.

11. It might have appeared rather bold, 15 or 20 years ago, to doubt, in the face of the evidence that had accumulated at that time, the potency of volcanic gases as heating agents. The pendulum has now apparently swung back, and Graton, following Shepherd (12), concludes that exothermic reactions fail as a source of volcanic heat. The arguments are both qualitative and quantitative. They appear convincing enough, and it seems clear that the reactions considered are not responsible alone for volcanic activity. Some objections could perhaps be raised to points of detail. But the main question is: have the proper chemical or physical reactions been considered?

12. To be sure, the present writer himself has concluded from a systematic and extended series of temperature measurements that the thermal effect of burning gases was slight

at Nyamlagira in 1938 (15). But he obtained at the same time spectrographic recordings of the volcanic flames which showed the occurrence of several N^2 bands with high excitation energies which are as yet unaccounted for. One plate revealed also very faint bands of an unidentified substance which is known to occur in comets. These observations lead one to suspect that our knowledge of volcanic gases may possibly be only an embryonic one. Anyhow, the fact that no reactions are known which could provide much energy at the surface does not imply that other reactions ($2H \rightarrow H_2$, $2N \rightarrow N_2$?) do not occur with important thermal effects at some depth.

13. A further indication of a knowledge insufficient to warrant any statement concerning chemical energy is provided by what may be called the water problem. Magmatic gases seem to consist dominantly of water. Now, as will be shown in the next section, water is precisely one of the most difficult elements to account for in the outer portions of the Earth.

THE WATER PROBLEM.

14. In the first place, if magmas result from remelting of crystallized rock (see § 19 the objections to the hypothesis of a molten, glassy layer in the crust) the amount of volatiles set free in the process of melting cannot be greater than the amount previously held in the rock. This amount would be, according to Shepherd (12), around 30 cc of gas at 1200° C and 760 mm. or, roughly, 0.5 percent, and would agree with the amount discharged at some volcanoes (15). But it would not agree with our conception, based on evidence outlined in § 9, of occasional and exceptionally water-rich magmas. An independent origin must be provided for this water, just as we must provide an origin for a number of less common metallic constituents that could hardly be accounted for if magmas result solely from remelting (see § 19, d). The problem is also connected with that of the origin of the oceans.

15. There are indeed reasons to believe that the crust and the mantle may have been originally entirely water-free. Such is the case for most, if not all, meteorites. It has been frequently pointed out that when the earth was gaseous it would have been unable to retain molecules with a thermal velocity greater than the velocity of escape from its gravitational field and would thus have lost most of its lighter con-

stituents. Jeffreys (reference 7, p. 147) accounts in this manner for the scarcity on earth of elements such as Xe and Kr which, being unable to become fixed in any heavier combination, would have been lost by diffusion into space. This would hardly appear probable, because if elements as heavy as Xe (130) were lost, then practically all the major constituents of the earth such as Fe (56) and SiO_2 (60) would have been lost also and there would be no earth at all.[2] On the other hand, Jeffreys (reference 7, p. 312) quotes Jeans to the effect that a gas with a mean square velocity of 2.5 km/sec would loose only one half of its amount in 2.10^6 years, which is a much longer time than it took the surface of the earth to cool down to its melting point. As the mean square velocity of hydrogen at 280° K is 1.9 km/sec. Jeffreys concludes that the Earth's gravitational field would have been sufficient to keep control of even the lightest elements of the atmosphere.

Now the rate of "evaporation" of the atmosphere into space should be proportional to a) the mean velocity u of its molecules, since all the molecules within a distance u from the evaporating surface and moving towards it will cross it within a second b) the ratio σ of the evaporating surface to the total volume of the gas c) the fraction β of the molecules which have a velocity greater than the velocity of escape from the gravitational field $v_e = \left(\frac{2GM}{R}\right)^{1/2}$ where G is the gravitational constant, M and R are the mass and radius of the Earth and d) possibly a dimensionless numerical constant n which, as most numerical constants, is probably of the order of 1. Then we write

$$\frac{dN}{d\theta} = n.u.\sigma.\beta.N \quad \ldots\ldots\ldots\ldots\ldots (4)$$

where N is the total number of molecules in the atmosphere, and the time in which half this number of molecules will have evaporated into space is

$$\theta_{1/2} = \frac{0.6932}{n.u.\sigma.\beta.} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

[2] It appears that the specific heat ratio for the gaseous earth cannot have been smaller than 4/3. The gas consisted thus essentially of mono-and di-atomic molecules.

The fraction β may be computed, assuming a Maxwellian velocity distribution and is

$$\beta = \frac{\int_{ve}^{\infty} 4\pi\left(\frac{m}{2\pi KT}\right)^{\frac{3}{2}} \sigma^2 e^{-\frac{m\sigma^2}{2KT}} d\sigma}{\int_{0}^{\infty} 4\pi\left(\frac{m}{2\pi KT}\right)^{\frac{3}{2}} \sigma^2 e^{-\frac{m\sigma^2}{2KT}} d\sigma}$$

where k is Boltzmann's constant, m the mass of a molecule and v its velocity. Remembering that

$$u = \left(\frac{3KT}{m}\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

we have finally

$$\beta = 1.38\,\frac{v_e}{u}\,e^{-\frac{3}{2}\frac{v_e^2}{u^2}} + 1 - erf\left(\frac{1.225v_e}{u}\right) \quad \ldots\ldots (7)$$

erf (x) being the usual error function $\frac{2}{\sqrt{\pi}}\int_0^x e^{-x^2} dx$. For $u = 2.5\times10^5$ cm/sec and $V_e = 11.28\times10^5$ cm/sec we find $\beta \cong 3{,}510^{-11}$. Assuming an atmosphere 70 km thick, σ is 14.45×10^{-8} cm^{-1} and

$$\frac{dN}{d\theta} \cong 1.26\times10^{-14} nN$$

$$\theta_{1/2} \cong \frac{5.5}{n}\,10^{13}\ sec$$

or about $\frac{1.83\times10^6}{n}$ years.

Let us see now what would happen in an entirely gaseous earth at a temperature of, say 6000°K. We suspect at once that the half life $\theta_{1/2}$ will be much smaller than 10^6 years, because a) u would be larger and b) v_e would be smaller, the radius R being greater in the gaseous state than in the solid one. Now it is clear from (7) that β and hence $\theta_{1/2}$ are very sensitive to the ratio $\frac{Ve}{u}$. Expressing v_e as a function of R, supposing

the mass M to be constant, and neglecting (1-erf), which is small compared to the other term in β, we find

$$\theta_{1/2} \cong 5.95 \times 10^{-12} \times R^{\frac{3}{2}} \times e^{\frac{1.1858 \times 10^{21}}{u^2 R}} \qquad \ldots\ldots(8)$$

For water vapor at 6000°K, u=2.88 10^5 cm/sec. Suppose that the radius of the gaseous earth was twice the present one, corresponding to a mean density of 0.69 g/cm^3. Then $\theta_{1/2} = 2.10^7$ sec, or less than a year. Thus if the earth has remained for more than a year in this gaseous state, it is probable that it has retained, at least in its outer portions, only a small fraction of the water vapor that it may have contained originally. It appears also that it could have retained only a small proportion of gases heavier than water, such as nitrogen or oxygen, $\theta_{1/2}$ for oxygen being 3.5×10^3 years.

The whole matter is rather uncertain because it remains to be seen whether the actual radius was twice the present one when the mean temperature T_m was 6000°K. The radius for an "Emden" model with polytropic index n and mean molecular weight $\bar{\mu}$ is (ref. 2, p. 88)

$$R = \frac{\bar{\mu} GM}{(5-n) 8.31 \times 10^7 . T_m} \qquad \ldots\ldots\ldots\ldots\ldots(9)$$

Remembering that $u^2 = \frac{3KT}{m}$ and that $v_e{}^2 = \frac{2GM}{R}$ we find for the half time of a gas with molecular weight μ the remarkably simple relation

$$\theta_{1/2} \cong 5.95 \times 10^{-12}\, R^{\frac{3}{2}}\, e^{(5-n)\frac{\mu}{\bar{\mu}}} \qquad \ldots\ldots\ldots(10)$$

where $\theta_{1/2}$ is a function of R and $\frac{\mu}{\bar{\mu}}$ only (n being usually taken as 3).

Suppose we start with an "earth" with the mass of the present one and a mean density equal to that of the sun (1.41). Then we find that gases with a molecular weight twice the average could have been retained only if the earth remained in that state for a matter of a few hours at most. Actually the earth must have expanded quite rapidly when it escaped from the sun's powerful gravitational field so that our result is not improbable. We really should have taken into account the surface temperature rather than the mean temperature, but

there is no means of calculating the former quantity. We feel certain, however, that when the crust of the earth began to form, its atmosphere contained practically no water and probably neither nitrogen nor free oxygen. All the oxygen present at that time must have been tied up in the form of heavier molecules, such as MgO, FeO, or SiO_2.

At 1000°C, the mean square velocity of water molecules is 1.33×10^5 cm.sec^{-1}, and since at this temperature the earth would be entirely condensed its radius would be very close to the present one. From that time on, water would have been retained almost indefinitely. This has led Jeffreys to suggest (op. cit., p. 312) that even if the present atmospheric gases had not been retained from the primitive earth, they might have been supplied since by volcanic action.

In the first place, the contribution of volcanoes to the oceans is at present very small. Taking the figures of § 4 for the amount of lava erupted since the close of the Precambrian and supposing that the lava contained 10% of water, a very high amount indeed, we find for the total amount of water discharged through volcanoes a maximum of 10^{22} gr., which is only a small fraction of the mass of the oceans. These figures do not suggest that volcanic activity on the usual scale could account for both the earth's atmosphere and hydrosphere.

On the other hand, if the atmosphere contained no water at the time of solidification, the rocks formed at that time would contain very little or none, and volcanic activity originating entirely in the solid portion of the earth could provide no more.

Since the oceans obviously exist,[3] the suggestion presents itself that their water must have originated in the deeper parts of the earth, i. e., the core. It is possible that they were formed by diffusion from this core of water and/or hydrogen which would have been retained in the central portion of the gaseous earth because 1) the escape velocity would be greater at the center than at the surface by an amount depending on the distribution of gravity with depth 2) the process of diffusion from the center would apparently be slow when compared to the rate of "evaporation" from the surface.

[3] An alternative suggestion is that the major planets may have picked up their atmosphere as they revolved through the gaseous medium formed by evaporation from the initial gaseous filament (ref. 10). This hypothesis would hardly account for the difference in composition of the atmosphere of the various planets.

Now diffusion may be roughly expressed by the relation $x^2=2Dt$, where x is the mean square distance travelled in time t by the diffusing molecules and D is a constant. For gaseous diffusion through solids at normal temperature D is usually of the order of 10^{-6} cm^2 sec^{-1}. Thus for $t=10^9$ years, x is of the order of 10^5 cm. only. D increases usually very rapidly with increasing temperature, so a faster rate of diffusion could be expected in depth, but diffusion through the upper mantle would be slow and could probably not account for the formation of the oceans in the required time unless it were helped by convection currents or movement along fracture planes.

16. The suggestion presents itself that diffusion, possibly helped by convection in the mantle, may still be going on at the present time, and that it might be responsible for the continued volcanic, magmatic, and metallogenic activity on the earth. Clearly all volcanic activity cannot be attributed to this cause, because such a cause would not exist on the moon, which shows nevertheless signs of intense volcanicity in the past. But volcanic activity appears to have ceased on the moon and it seems possible that it would have ceased also on the earth at an early stage of its history, were it not for some cause which does not exist on the moon and which must therefore, most probably, be located in the earth's core.

The present writer feels that the problem of the origin of magmatic water has not received so far a sufficiently thorough treatment and that, accordingly, the statement that chemical reactions have nothing to do with volcanic activity appear to be insufficiently substantiated as yet.

INTERNAL HEAT.

17. The alternative to chemical energy, as a cause of volcanic activity is, in Graton's views, to rely on "internal heat." What is meant by this is not quite clear to the present writer; he takes it to be the thermal energy stored up in the depths of the Earth and evidenced by the prevailing temperature gradient. It remains to be seen how this energy could be made available for our purpose.

18. Daly has put forward the hypothesis that there may exist at moderate depths (about 60 km) a liquid basaltic layer behaving, because of the prevailing pressure, more like a glass than like a true liquid. Daly has given much evidence in support of this hypothesis, the main argument being that the

unity of volcanic action and the repeated recurrence in time and space of eruptions of predominantly basaltic character point to a uniform, worldwide source for all magmas. The existence of molten magma at moderate depth would of course provide a very simple way of transferring "internal" heat to the surface.

This hypothesis, however, is not supported by the evidence at present available.

19. a). The problem of obtaining in this layer the required viscosity and rigidity is a difficult one. It is true that Bridgman's well-known experiments have indicated that viscosity rises rapidly as a function of pressure, but these same experiments indicate also that when the temperature and pressure are raised simultaneously so as to keep the volume constant, the viscosity as a rule decreases. Let us see what this means when applied to a basaltic liquid under the conditions postulated by Daly (pressure 17,000 bars, temperature 1200°C.). The temperature-pressure gradient corresponding to a constant volume is such that

$$\frac{dT}{dP}=\frac{\chi}{a}$$

where χ is the compressibility and a the thermal expansion. Put $a=35\times10^{-6}$, $\chi=1.45\times10^{-6}$ and $dP=1.7\times10^{4}$; then $dT=700°C.$ This means that the viscosity of a basaltic liquid at one bar and 500°C. is, if anything, greater than its viscosity at 17,000 bars and 1200°C. Now the viscosity of basalt at 500°C. is probably of the order of 10^{12} or 10^{13} c.g.s.; thus the viscosity in the basaltic layer, being less than this, is not consistent with the viscosity, of the order of 10^{22} or 10^{23}, required by the geological time-scale for isostatic adjustments (8).

b). If this basaltic intermediate layer is to be liquid, its temperature is by definition higher than its melting point at the prevailing pressure, and thus considerably (about 300°) higher than the melting point at atmospheric pressure. Taking into account possible effects of the expansion (see § 7) it appears that a basaltic magma originating in this layer would reach the surface with a certain amount of superheat. Now one of the very few valid generalizations in volcanological science is that the temperature of eruption is always within the melting range corresponding to the given lava, as indicated by actual measurements (16) and the almost universal occurrence

of phenocrysts of intratelluric origin; there are, as yet, no known examples of superheated lavas.

c). Available thermal data do not seem to indicate that the melting point of basalt may be reached at depths where the composition, judged by seismic data, may be basaltic (see, for instance, ref. 4, p. 483).

d). There may be insuperable difficulties in attempting to derive all known magmas from a single, common source. One of these difficulties lies in the principle of petrographic and metallogenic provinces. If all magmas originate in one layer, why should they be different? Various mechanisms of differentiation may account for some variation, but why should any one mechanism operate in a great many instances in a given region, and rarely elsewhere? Local conditions, and notably the composition of the crust may control to some extent the final composition of magmas, but it would remain difficult to explain the recurrence in geological times at the same place of magmatic cycles of different affiliations. Furthermore, although local conditions might control, by assimilation or otherwise, the composition of magmas as far as certain common elements are concerned, why should rarer elements, such as tin for instance, become concentrated in a small number of granitic intrusions, the majority of such intrusions being, for all practical purposes, devoid of this element? If it is contended that these rare elements existed in the crust previously to the intrusion and were merely picked up by the magma on its way up, then how are we to explain the occurrence of such rare elements only in the second, or third major magmatic episode in a given region? Local conditions of crystallization could hardly be called upon, for we find tin associated with other more common minerals, indicating that the conditions which prevailed at the time of tin deposition were similar to those that have obtained in a great many tin-free deposits.

In the writer's mind such facts can hardly be explained on the assumption that all magmas are derived from a common uniform layer; it seems more probable that they must have several parents, variable in origin and composition.

20. Whatever the reader's decision on the subject of a "liquid" layer may be, it remains that some manifestations of volcanic activity may be interpreted as resulting from local melting.

a) As has been mentioned before, the measured temperature of lava flows invariably seems to be lower than the melting point, in the melt considered, of the most refractory mineral or minerals which may result from the crystallization of the lava. This fact may be interpreted easily if lavas result from some process of crystallization differentiation, but would not apply to the parent (basaltic?) magma itself (see § 19, b). The same relation would occur if the extrusion of lava at the surface resulted from the volume increase (about 10%) attendant upon melting.

b) That an actual dilatation of the volcanic edifice does occur before an eruption has been shown instrumentally at Kilauea and by the movements of the shore-line at Vesuvius.

At the beginning of the 1938 eruption of Nyamlagira, a rift was formed, about 600 meters long and roughly concentric to the crater, but somewhat lower down on the slope of the volcano. The inner side of the rift was pushed up and the outer side depressed, the total displacement amounting to several meters. As a result of these movements, the average slope was slightly reduced above and beneath the rift. This fracture is believed to have resulted from previous warping. Now the writer has observed at many other places on the volcano that rather steep slopes alternate with more gently inclined terraces, seven such steps being conspicuous notably on the south-western side of the mountain. It would appear thus that on several occasions the mountain swelled to an extent greater than could be taken care of by the elasticity of the structure. Rupture occurred, corresponding perhaps superficially to the formation of cone sheets at greater depths.

Such a swelling could hardly be accounted for by gas pressure, because of the eminently porous structure of volcanoes. The alternative suggestion is that the magma itself must have been expanding, as recorded at Nyamlagira by the gradual rise of the lava level in the crater during the years that preceded the eruption. This expansion might result from local melting.

21. Although it is clear that some magmas must have originated at great depths, there seems to be much evidence indicating that the "reservoir" of a volcano may be located at very shallow depths.

a) Erosion in the Tertiary volcanic districts of Scotland reveals lavas at present lying at the same level as the

"roots" of the volcanoes from which they were erupted and which consist of a complex of plutonic rocks (frequently ring dykes) and agglomerates corresponding doubtlessly to volcanic vents. The depth at which cone sheets would converge, and which indicates the position of the top of the magma reservoir, is at most a few kilometers.

b) Nyamlagira and Nyragongo are neighbors in the Virunga group; their craters are only about 12 km. apart. Their lavas, although overlapping at some places, are easily distinguishable because Nyragongo products invariably contain nepheline and/or melilite, which are conspicuously absent from the Nyamlagira lavas. Clearly, each of these volcanoes has an independent reservoir, in which different reactions are taking place. If these reservoirs were very deep, the channels leading upwards would undoubtedly communicate at various levels, and mixed types of lava would be found.

c) Rittmann, (11) from a study on assimilation and on the nature of ejected blocks, concludes that the top of the magma reservoir at Vesuvius is at a depth of no more than 6 km.[4]

If we compare this evidence for the generation, or at least for partial generation, of magmas very near the surface with the existing evidence that some magmas rise from greater depths (see, for instance, the evidence brought forth by the inclusions in diamond-bearing kimberlites) we come to the conclusion that magmas are formed at various levels in the earth. If this be true, then the temperature gradient is probably of little or no importance, and some factors additional to pure

[4] There might be a rather simple means of testing this hypothesis of superficial melting. For suppose that magma is generated at a shallow depth within the crust and that it rises to the surface mainly because of the density difference between lava and country rock. Then it is obvious that the absolute height reached by the lava should depend on the amount of epeirogenic rising suffered by the crust, including the magma reservoir. Thus, if our hypothesis is correct, the altitudes of the summit of all continental volcanoes, plus or minus the amount of rising or lowering of the crust since the beginning of volcanic activity, should cluster around a mean value which could be used to find the average depth of the focus. The average for oceanic volcanoes should be different, because the density of water is less than that of the crust.

For instance, the tremendous altitude reached by some Andes volcanoes could be explained more easily if the source of the magma had risen by the same amount as the surface on which the volcanoes are built.

The geological and physiographical data required for the suggested compilation are unfortunately not available to the writer at present.

"internal" heat must be sought for. This suggests again a multiple parentship. Diffusion from the inner core has already been mentioned as one of these "parents" responsible mainly for magmatic water, less common metallic constituents and possibly a large part of volcanic energy. An additional factor may be just chance.

STATISTICAL MELTING.

22. Let us pause for a moment and consider briefly the results obtained so far. They all seem to point to randomness: the water content of magmas varies between wide limits, rare elements are distributed most unevenly, magmas appear to originate at various levels in the crust and, furthermore, the location of volcanoes is quite irregular. It is true of course that many active volcanoes are located in orogenic or tectonic belts, but some orogenic belts are not volcanic (e.g. the Alps, Himalaya). "Plateau" eruptions, which are the most striking volcanic phenomena we know, occur more or less at random in undisturbed regions and at times of relative tranquility. This would appear to exclude any tectonic factor, such as frictional heat, as a main cause of volcanic activity. The distribution of volcanoes in time seems to be quite random also.

Obviously, nothing can be gained by attempting to explain all volcanic activity in terms of a single magma endowed with more or less standard properties which may well be a creation of petrologists rather than of Nature.

The present writer believes that this very randomness and diversity of volcanic and magmatic action is one of its most striking features. Diversity could be explained by assuming that several factors of variable relative importance contribute to the process. Randomness suggests that there must be an element of chance.

As the connexion between volcanoes and chance might appear rather obscure at first, it may be useful to indicate roughly what relation might exist between probability and, say, melting.

23. Remembering the facts presented in paragraph 4, the following question may be raised: could there be a probability of the order of 10^{-9} or 10^{-10} of the occurrence of local temperature deviations from the mean in a given layer, sufficient to explain volcanic activity?

What is meant by this may be mac analogy. If we mix two liquids consisti molecules and stir properly, the mixture w pink color. Suppose now we take smallei of this liquid; when we come down to sa molecule, each of these will be either red o A sample the size of two molecules migh pink. A sample the size of ten molecules ent shades of color, including red and whit for the occurrence of extreme deviations f would of course be much smaller than in sample.

In the same manner consider a gas temperature but a certain distribution of molecules. Suppose we consider a very gas containing by chance only molecules n greater than the average; we would the temperature of this part of the gas is g temperature of the gas as a whole.

The problem is one which is dealt w theory of fluctuations. The basis for tl known principle that the probability of

with energy Ei is proportional to $e^{-\frac{Ei}{\kappa T}}$ result that the probability f(x) that a take a value x is

$$f(x) = \sqrt{\frac{a}{\pi}}\, e^{-a(x-x_0}$$

where x_0 is the mean value of x and a is the

$$a = \frac{1}{2KT}\left[\frac{d^2E}{dx^2} - T\frac{d^2}{dx}\right.$$

k being 1.379×10^{-16} erg/1°, E and S ı internal energy and the total entropy of th square deviation $\overline{(x-x_0)^2}$ is $\frac{1}{2a}$ (see, fo

24. Suppose now that x is the temperatu of the crust with mass M, energy $\overline{E}$ unit mass. Suppose we want to finc

for a deviation of, say 200°C. from the mean. Then we must have

$$10^{-10} = \sqrt{\frac{a}{\pi}}\, e^{-a\,4\,10^4}$$

or

$$a \cong 4.5\,10^{-4}$$

Put T=1000°C. and M=10^{15} gr. Then

$$\frac{d^2\bar{E}}{dT^2} - T\frac{d^2\bar{S}}{dT^2} \cong 10^{-31}$$

a quantity so small that for all practical purposes

$$\frac{d^2\bar{E}}{dT^2} = T\frac{d^2\bar{S}}{dT^2} \qquad (13)$$

Since we are interested in fluctuation in a given layer, i. e., at constant pressure, we find from (13) the condition

$$\frac{Cp}{T} - P\left(\frac{d^2v}{dT^2}\right)_P = 0$$

or

$$\frac{Cp}{T} + P\left(\frac{dCp}{dP}\right)_T = 0 \qquad (14)$$

If there exists a layer for which the pressure and the specific heat satisfy (14), we may expect to find in this layer important statistical deviations from the mean temperature.

For most solids $\left(\frac{d^2V}{dT^2}\right)_P$ is positive, so that c_p decreases with increasing pressure.

a) Suppose in the first place that this decrease is linear, and let P^1 be the pressure at which C_p becomes O. Bridgman (Physics of High Pressure, p. 175) estimates that this pressure would be of the order of 10^8 or 10^9 bars for most metals. We write then

$$C_P = C_P^0 - \frac{C_P^0}{P^1}P$$

where C_p° is the specific heat at zero pressure. Then $\left(\frac{dC_P}{dP}\right)_T = -\frac{Cp_0}{P^1}$ and relation (14) is satisfied for a pressure

such that

$$P = \frac{1}{2} P^1$$

which is of an order of magnitude that is probably not obtained in the mantle.

b) Suppose now that C_p decreases initially more rapidly than linearly, then more slowly. For the sake of convenience, let us write

$$Cp = Cp^0 \quad e^{-aP}$$

which gives $C_p = 0$ only at infinite pressure. Then

$$\left(\frac{dCp}{dP}\right)_T = -aC_p^0 e^{-aP}$$ and (14) is satisfied if

$$P = \frac{1}{a}$$

If C_p decreases by 5 per cent in the range $0-10.000$ bars, then $a = 5\ 10^{-6}$ and $P = 2.10^5$, corresponding to a depth of about 600 Km.

If C_p decreases by 5 per cent in the range $0-1000$ bars, then $P = 2.10^4$, corresponding to a depth of 70 Km. or so.

This supposes that C_p is a function of the pressure only. If the thermal gradient in the earth were taken into account, the pressure that would satisfy (14) would probably be greater than if the temperature effect on C_p is omitted.

25. The problem we are interested in is not only one of temperature, but also one of heat; we want to find not only hotter masses but also molten masses. The best way to do this is to consider entropy fluctuations rather than temperature deviations.

The equation corresponding to (13) is then very simply

$$\left(\frac{d^2\bar{E}}{dS^2}\right)_p = 0 \quad \dots\dots\dots\dots\dots\dots (15)$$

This leads to the relation

$$1 - \frac{P}{Cp}\left(\frac{dV}{dT}\right)_p\left[1 + \frac{T}{Cp}\left(\frac{dCp}{dT}\right)_p\right] = 0$$

or, remembering that the thermal expansion α is defined as

$$1 - \frac{P\alpha}{\rho Cp}\left[1 - \frac{T}{Cp}\left(\frac{dCp}{dT}\right)_P\right] = 0 \quad \ldots\ldots\ldots (16)$$

where ρ is the density.

To find the order of magnitude of P, we suppose that C_p varies roughly by one half for a temperature change of 1000° (for instance from 0.2 cal/gr.1° at 0°C to 0.3 cal at 1000°C). Then $\frac{T}{Cp}\left(\frac{dCp}{dT}\right)_p$ is equal to $\frac{T}{2.10^3}$ and is of the order of 1 in the upper mantle. Then $P = \frac{\rho Cp}{2\alpha}$. Neither C_p or α are known as a function of depth, but if we take the surface value $\rho=3$, $C_p=0.3$ cal/gr.1°, $\alpha=2.5\times10^{-5}$, we find $P=7.5\times10^5$ bars. It does not appear entirely impossible that statistical melting might occur somewhere in the depths of the mantle.

The reader must be reminded that, according to equation (11), the probability of a given deviation above the mean is the same as that of a deviation below the mean. This means that heat keeps on flowing from one part of the system to another, the average temperature remaining constant. Now if melting occurs and if, because of gravity, the liquid portion begins to rise, then equilibrium is disturbed and the layer tends as a whole to lose heat. This is roughly what happens also in a gas containing molecules with a thermal velocity greater than the velocity of escape from the earth's gravitational field: the faster molecules escape and the gas as a whole must loose heat.

26. We may be interested also to find, by the same method, the fluctuations in composition that might be expected in a solution.

If n_i is the number of moles of component i in a given volume of the solution, remembering that $\left(\overline{n_i - n_i^0}\right)^2 = \frac{1}{2a}$, we see from (12) that the fluctuations at constant temperature and volume become infinite if

$$\left(\frac{d^2E}{dn_i^2}\right)_{T,v} = T\left(\frac{d^2S}{dn_i^2}\right)_{T,v} \quad \ldots\ldots\ldots\ldots (17)$$

Now (17) may be written

$$\frac{d^2}{dn_i^2}(E-TS)_{T,v} = \left(\frac{d^2F}{dn_i^2}\right)_{T,v} = \left(\frac{d\mu i}{dn_i}\right)_{T,v} = 0 \quad \dots (18)$$

μi being the chemical potential of i. Now the condition $\left(\frac{d\mu_i}{dn_i}\right) = 0$ is the usual condition expressing that component i is becoming immiscible in the solution. This is precisely what we might have expected: composition fluctuations become very great when a critical mixing point is reached, since at this point the solution breaks up into two phases of different composition.

27. Lest the reader may feel that we have introduced a mathematical fiction unrelated to any real physical process, it may be necessary to explain more clearly what the physical principles are.

The example of paragraph 26 shows that the condition $a=0$ really has a physical significance. We may give another familiar example: the density fluctuations in a gas. The density of a gas may be defined by the number of molecules in a given volume. Now the molecules in a gas are constantly moving, so if we consider a very small portion of the gas, we cannot be sure that the number of molecules in this volume will be the same a few moments later, nor can we be sure that this number would be the same in another similar volume somewhere else in the gas. Thus we may expect quite naturally that the density of any very small portion of the gas will fluctuate both in space and time. If we attempt to estimate these fluctuations by equation (12), we find that they are exceedingly small except in one case: they become very large if the gas is at its critical point. This is what we should expect without any reference to mathematics: at the critical point a gas is really neither a gas nor a liquid, but both at a time. It behaves much as an emulsion of liquid in gas, and the density fluctuations are evidenced experimentally by the well-known opalescence of critical fluids. Again in this case our probability has a very definite physical meaning.

Temperature fluctuations may be explained physically in the same manner. The molecules of a solid at a given temperature are vibrating, but the vibrational energy is not the same for all molecules. There is a certain distribution just as there is a

velocity distribution among the molecules of a gas. Some molecules have higher energies than others, but the same molecule does not retain indefinitely its high or low energy. This energy is constantly flowing back and forth, and when we say that a solid is in thermal equilibrium, we merely state than *on the average* the heat flowing in one direction is exactly equal to the heat flowing in the opposite direction. This does not mean that a very small portion of the solid does not take up at one time slightly more energy than a neighbouring portion. Consequently its temperature may be slightly higher. In particular, if the specific heat is very small, any infinitesimal flow of energy from one part of the solid to the other would result in very large temperature differences. Equation (14) shows that the same situation would occur even if $C_p \neq O$, provided there exists a certain relation between P, T, C_p and its pressure coefficient.

Equations (14) and (16) express thus merely the conditions under which notable fluctuations may occur; if these "critical" conditions are fulfilled, the probability of notable fluctuations is great. Now if this probability is great, we should be very surprised indeed if the event did not materialize at least once in a great many trials. For instance, if we consider a "unit" of lava and the crust which consists of 10^{10} such units, we feel sure that at least one of these units will show the deviation we are looking for, provided its probability is great enough or, in other words, provided equations (14) or (16) are satisfied.

What we want to point out is that, even at equilibrium, and provided certain conditions are fulfilled, a small part of a very large mass may be molten although the mean temperature of the mass is below its melting point. We are not prepared to state that this is a cause of volcanic activity, but what we wish to emphasize very strongly is that under certain circumstances *it may be dangerous to infer from a given property (e.g., temperature) of a large mass (e.g., the crust) that each and every microscopic part of this mass (e.g., a lava unit) must have exactly this same property.* There shall always be "flaws" which may become important when certain conditions are reached. This does not necessarily transgress the laws of thermodynamics: when a system is in equilibrium we state that its entropy as a whole is a maximum for a given energy and

volume, but we do not state that the entropies of all infinitesimal parts of the system are equal.

CONCLUSION.

28. How this notion of small-scale heterogeneity could be translated into a workable model of a volcano is precisely one of the problems which this paper intends to present and not to solve. What the writer wants to point out is that volcanic activity is

a) a small-scale, almost insignificant, phenomenon when compared to the earth as a whole

b) a process that is extremely diversified and more or less random, both in space and time.

It follows from a) that we cannot expect to find a reasonable explanation of volcanic action before the essential processes occurring within the earth are known with much greater precision than at present. No one would give any weight to the last cent on a balance sheet if the number of millions is imperfectly known. It follows further from b) that there must be more than one factor involved and that it is probably useless to attempt an explanation of volcanic activity by referring exclusively to our standard, rather rigid, concept of a magma. The writer has suggested two possible factors: diffusion from the core and local, small-scale, random deviations of various physical properties from their mean value, these mean values being the only ones accessible at present to our investigations.

The picture that suggests itself as a possible outcome of this discussion might be something like this: a) random occurrence of "flaws" at an appropriate level in the mantle; rise by gravity of the molten masses which might, because of their relatively high density, be unable to rise into the crust; transfer of heat from these molten masses to the surrounding rocks at their place of rest; local generation of gas-poor magmas b) diffusion of ionized and atomic elements from the core, in connection or not with the rise of molten masses; physical reactions generating heat (and water ?) presumably at the level where intracrystalline diffusion ceases and free movement in pores or along fracture planes begins; chemical reactions with surrounding rocks and local generation of gas-rich or entirely gaseous "magma"; ore deposition c) all combinations of a) and b) in variable proportions.

It is believed that investigations along these lines, whether or not they substantiate the present hypothesis, might provide a useful approach to the subject of volcanic activity.

In conclusion, the author wishes to express his best thanks to Prof. A. Holmes, who has read and criticized the manuscript and made important comments and suggestions. Full responsibility for controversial statements rests with the present writer.

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DROWNED ANCIENT ISLANDS OF THE PACIFIC BASIN.*

H. H. HESS.

ABSTRACT. Some one hundred and sixty, curious, flat-topped peaks have been discovered in the Pacific Basin between Hawaii and the Marianas. They appear to be truncated volcanic islands rising about nine to twelve thousand feet from the ocean floor. The flat summit levels generally range from three to six thousand feet below sea level. Some less well-developed ones are deeper. The flat upper surface is commonly bordered by a gently sloping shelf a mile or two wide. The summit surfaces are apparently not all of the same age since adjacent peaks may have flat tops which differ in elevation by as much as a thousand feet, though in some cases groups of peaks do have the same elevation. The relationships to atolls of the Marshall Islands group indicate that the surfaces are older than the atoll formation. An hypothesis is tentatively advanced suggesting that the summit surfaces are very old and possibly represent marine planation surfaces in a Pre-Cambrian ocean in which reef building organisms did not exist. It is suggested that the present depths of the surfaces may be accounted for by the relative rise of the ocean surface as a result of accumulation of sediments on the floor. Thus the deeper the surfaces are the greater their age.

PART I. DESCRIPTION.

A LARGE number of curious, flat-topped peaks have been discovered scattered over millions of square miles in the Pacific basin. These peaks are roughly oval in plan and their slopes suggest volcanic cones. The remarkable feature about them is that they are truncated by a level surface which now stands approximately 750 fathoms (4500 feet) below sea level. For convenience in discussing these submerged flat-topped peaks which rise from the normal ocean floor, the writer will henceforth call them "guyots" after the 19th century geographer, Arnold Guyot.

Betz and Hess (1942) discussed the major features of the floor of the North Pacific. This was in the nature of a broad areal reconnaisance of the largest features of this extensive region. Since 1942, Hess has spent two years at sea in the western Pacific and has thus had the opportunity to fill in some details which bring to light many new relationships and necessitate some modification of ideas originally set forth. The

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data presented in this paper were obtained on random traverses incidental to war-time cruising on the U.S.S. Cape Johnson. What passed beneath the ship was recorded but it was not feasible to investigate further such interesting features as were encountered. Nevertheless it is evident that much information can be obtained on the geological history of an oceanic area by judicious use of available techniques. It is a vast and intriguing field for research under more auspicious peace-time conditions.

SCOPE OF PRESENT INVESTIGATION.

From random sounding traverses across or merely grazing guyots an attempt will be made to construct a picture of their physical features. The data collected on the cruises of the Cape Johnson have been supplemented by soundings obtained from the files of the Hydrographic Office, U. S. Navy. The origin and age of the flat upper surfaces of guyots represent the main problem of this paper. Secondarily the relation of guyots to atolls of the northern Marshall Islands will be discussed.

AREAL DISTRIBUTION OF GUYOTS.

The distribution of known and suspected guyots is shown in Fig. 1. Roughly they are known to occur north of the Carolines and east of the Marianas and Volcano Islands between latitudes 8° 30′ North and 27° North and longitudes 165° West to 146° East. None has been found west and south of the above boundaries though this area has been at least as well explored as the former. North and east of the region outlined above it appears from scattered soundings that the area containing guyots does extend to 45° North and 165° West. Some of the seamounts in the Gulf of Alaska described by Murray (1941) almost certainly are guyots whereas others appear to be of a different character. Twenty bona fida guyots were encountered at sea by the writer and some 140 more are indicated by soundings on Hydrographic Office charts and documents. Considering sparseness of deep sea soundings in parts of the area mentioned above, it is likely that a large number of undiscovered ones are present.

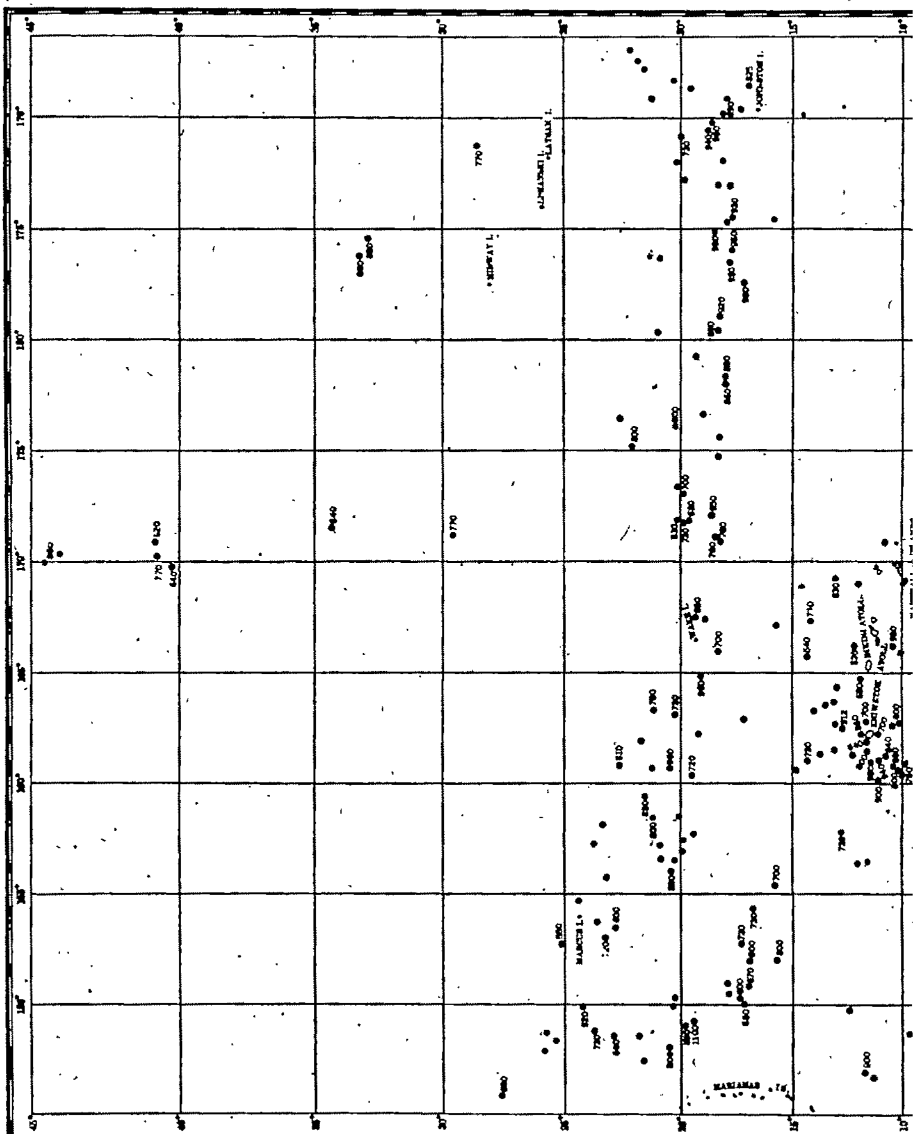

Fig. 1. Areal distribution of guyots in the western and central Pacific. The numerals next to some of the guyots indicate the depth in fathoms to the flat upper surface.

PHYSICAL FEATURES OF GUYOTS.

One of the best profiles obtained across a guyot was one encountered south of Eniwetok on October 6, 1944, in latitude 8° 50′ North, longitude 163° 10′ East. This guyot is about 35 miles in diameter at the base, and the truncated upper sur-

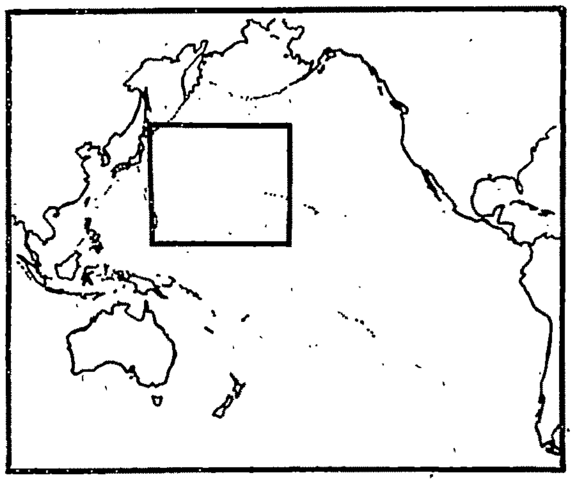

Fig. 1A. Index Map showing area included in Fig. 1.

face is about 9 miles in diameter. The top is remarkably flat at a depth of 620 fathoms.[1] The outer rim of the top is bevelled by a gently sloping shelf one or two miles wide (slope 2° to 3°). The outer margin of the gentle slope is about 70 fathoms deeper than the inner margin. This gentle slope breaks abruptly to 22° at its outer margin. The profile from the edge of the shelf to the normal ocean floor at 2600 fathoms is, as might be expected, concave upwards. From an average of 22° at the top it gradually decreases in steepness until it forms a smooth tangent with the ocean floor at the bottom. Figure 2 (A and B) below is a reproduction of the sounding traverse across the guyot.

Guyots vary widely in size. One a few miles northeast of Eniwetok has a flat summit only a couple of miles across (latitude 11° 45′ North, longitude 162° 55′ East); whereas one

[1] NOTE: All soundings mentioned in this paper are uncorrected for salinity, temperature and pressure and were taken with fathometers set to a speed of sound in the sea water of 4800 feet per second. The corrections would be too small to be of significance in this discussion.

some distance farther northeast apparently has a flat upper surface 35 miles wide and has a diameter of 60 miles at its base (latitude 14° North, longitude 167° 30′ East). In general they

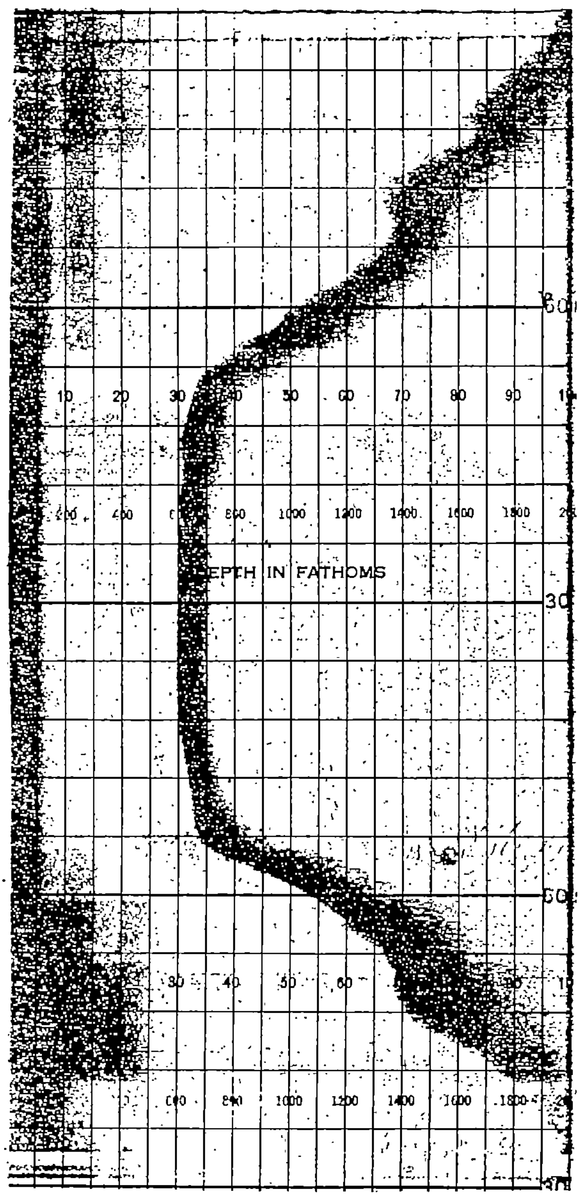

Fig. 2A. Fathometer recorder trace of a typical guyot. Note irregularities on lower slopes with considerable thickening (lengthening) of the echo trace. These indicate steep slopes to the side (parallel to ship's course) and necessitate an adjustment to obtain the approximate depth immediately beneath the ship. The adjustment has been made in Fig. 2B below.

appear to be circular or oval in plan. No correlation has been noted between the depths of the flat upper surfaces and the depths of the surrounding ocean floor which normally ranges from 2600 fathoms (15,600 feet) to 3100 fathoms (18,600 feet). The observed depths of the flat upper surfaces of typi-

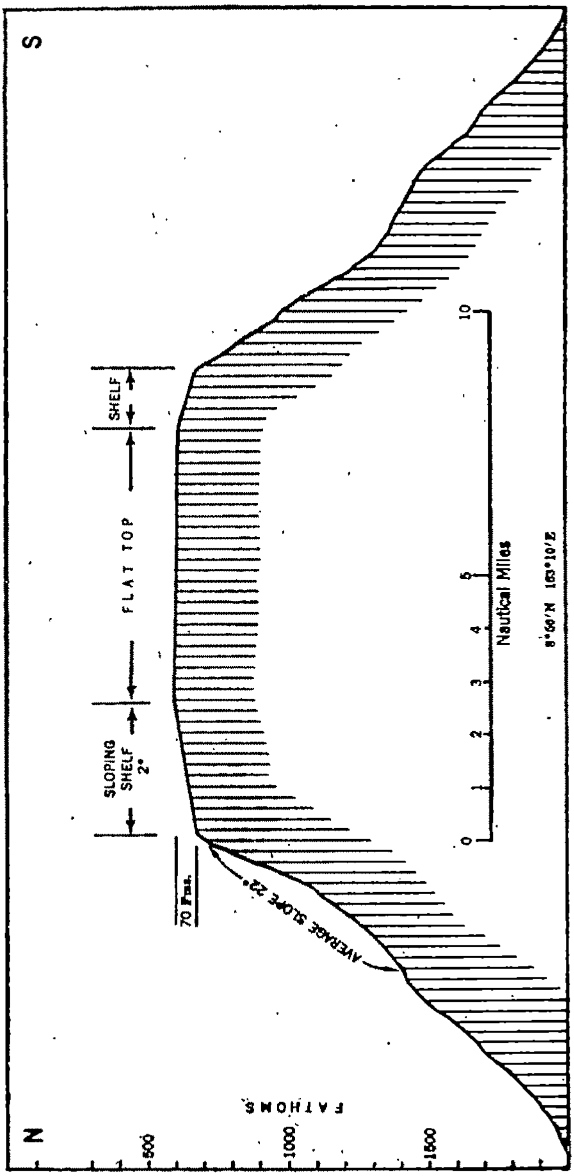

Fig. 2B. This diagram was traced directly from Fig. 2A and adjustments, for steep slopes to the side, made. The vertical and horizontal scales and numerical values of the slopes in degrees are given.

cal guyots range from 520 fathoms (3120 feet) to 960 fathoms (5760 feet), with most values concentrated near the center of this group (800 fathoms). Thus the guyots rise from 10,000 to 15,000 feet above the ocean floor. The flat tops of guyots in general do not exhibit accordance of summit levels.

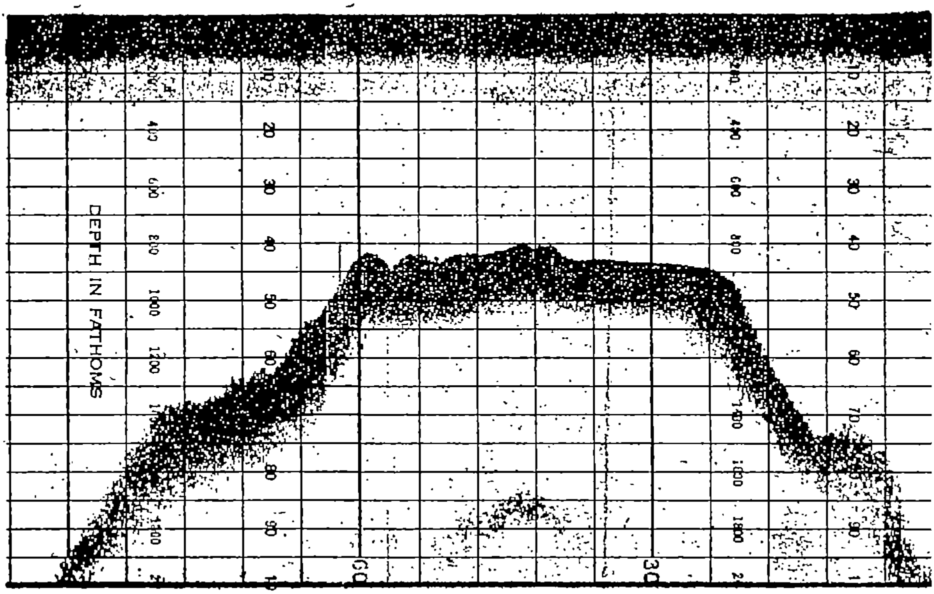

Fig. 3A. Guyot showing hummocky type of upper surface.

It is quite common to find groups of guyots in a relatively small area with flat tops varying several hundred fathoms from one to another among the group. Less commonly two or three guyots in a group will have approximately the same depth.

A few guyots were found to have upper surfaces which were gently undulating rather than flat. These undulating or hummocky surfaces have a maximum relief of about 40 fathoms. In most cases the flat surface can be seen here and there in the profiles and it passes *beneath* the hummocky material (Fig. 3). Judging from the evidence most guyots have been swept clean of the fine sediments which must be continually settling upon them. In the case of the rare, hummocky ones it would appear that the fine precipitates had for some reason not been completely swept off. It is rather surprising that the normal guyots are swept clean since water currents at such depths as these are thought to be slight. One must look to occasional bottom

stir up by tsunami (Bucher 1940) though possibly currents related to tides might be strong enough. Once the sediment on these isolated, flat-topped peaks is stirred up, very little of it would be expected to fall back on top of the guyot. It would be dispersed over the surrounding area.

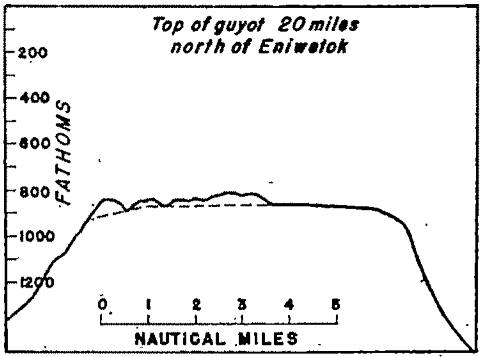

Fig. 8B. Tracing of fathometer record shown in Fig. 8A adjusted and with scales indicated.

Though few guyots show any suggestion of terraces on their outer slopes, one large guyot near latitude 20° North, longitude 148° East has a well developed flat upper surface at 800 fathoms and projecting from under its southeastern margin there appears to be a terrace or older guyot with a flat upper surface at 1100 fathoms. In the area between Wake Island and Johnston Island there are a number of normal guyots rising from hilly areas which have numerous flat or nearly flat surfaces between 1100 and 1900 fathoms. These hilly areas with flat or nearly flat surfaces have as yet been insufficiently explored to understand the relationships they exhibit. They may represent areas of older, deeper guyots partly buried by sediments, but until a more detailed examination of them can be made, their nature will have to remain rather obscure. Such areas do not appear to be common elsewhere. Some of Murray's Gulf of Alaska seamounts possibly also fit into this category. The great majority of guyots rise from the normal ocean floor.

RELATION OF GUYOTS TO ATOLLS IN THE MARSHALL ISLANDS.

Many guyots are present in close association with atolls in the northern Marshall Islands. The present discussion is cen-

tered about Eniwetok Atoll of that group. This atoll apparently rests in part upon two guyots so that the flat upper surfaces of the guyots project out beneath its southern and

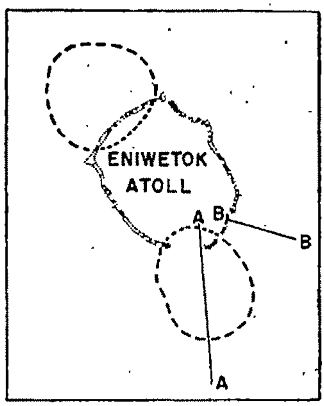

Fig. 4. Relation of Eniwetok Atoll to two nearby guyots which are outlined on the diagram by dashed lines.

northwestern slopes resulting in a well developed bench on those sides at a depth of 700 fathoms. The eastern side of Eniwetok shows a normal atoll slope with no suggestion of a bench, and the central portion of the western side shows similar features.

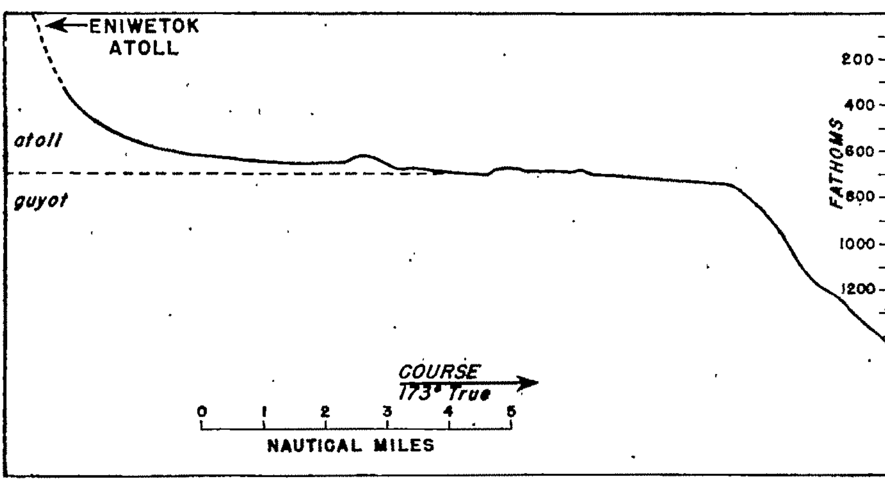

Fig. 5. Tracing from fathometer recorder of traverse extending southward from Eniwetok showing the atoll presumably superimposed upon a guyot (A-A of Fig. 4).

Figure 4 shows the relationship between Eniwetok Atoll and the nearby guyots, and figures 5 and 6 show two profiles, one approaching the passage between Japtan and Parry Islands from the east and the other approaching Wide Passage at the south end of the atoll from the south, which shows the guyot apparently disappearing beneath the atoll slope.

The absence of a 700 fathom bench locally around part of Eniwetok Atoll strongly suggests that the atoll and its vol-

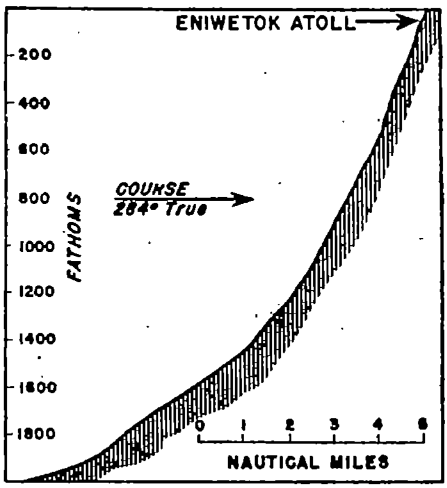

Fig. 6. Profile B-B of Fig. 4, showing normal atoll slope approaching Eniwetok from the East.

canic core are younger than the benches which project from its southern and northwestern sides. The whole structure of the atoll, in other words, seems to have been superimposed upon the older and already existing, surface of the guyots. Since it can, without too much license, be assumed that the other nearby atolls of the Marshall group developed simultaneously with Eniwetok, their slopes might be examined for 700± fathom benches for further substantiation of the age relations postulated above. Only two of these have been adequately charted, Majuro and Kwajalein, and neither of them shows 700 fathom benches. When it is considered that a relatively small atoll such as Majuro shows no bench at 700 fathoms while not very far away a guyot has a truncated upper surface

35 miles across, it is evident that Majuro could never have been subjected to the conditions which planed off the 35-mile-wide surface of the guyot.

Part II. Theory.

The writer has given a great deal of thought to the problem of origin of guyots since first encountering them in 1944. In Part I of this paper the physical features of guyots so far as they are known, are described. It now remains to account for

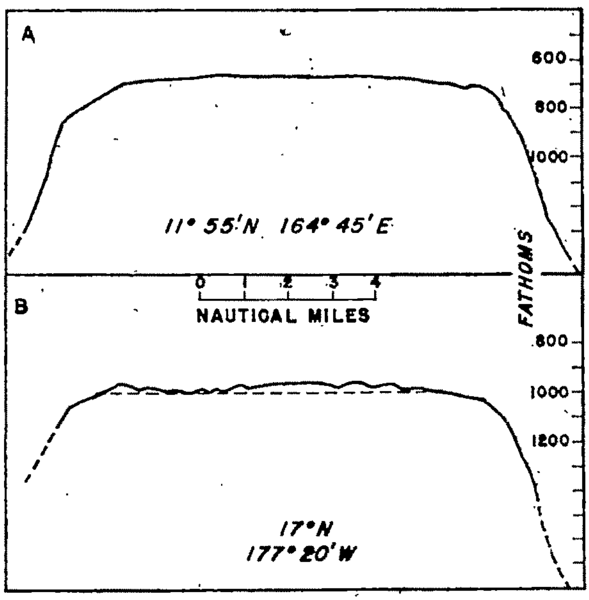

Fig. 7. Profiles across two guyots; A is normal except that the gently sloping shelf is lacking on the right hand side, B is an example of the hummocky type of upper surface.

them. During the past two years, many hypotheses were tried and discarded. Finally the writer arrived at the hypothesis here presented. Though it explains the facts at present available, it is highly speculative and might easily be wrong. Nevertheless, it seems worth presenting as a working hypothesis, particularly since it has many interesting ramifications some of which would be worthy of investigation even if the parent hypothesis were found to be invalid.

EXPLANATION OF DEVELOPMENT OF UPPER SURFACE OF GUYOTS.

When the writer first discovered guyots, he supposed that they were drowned atolls. However, this hypothesis proved untenable upon further study. A profile of an atoll should show a rise along the outer margin representing the area of active reef growth and should be dished in the middle, the

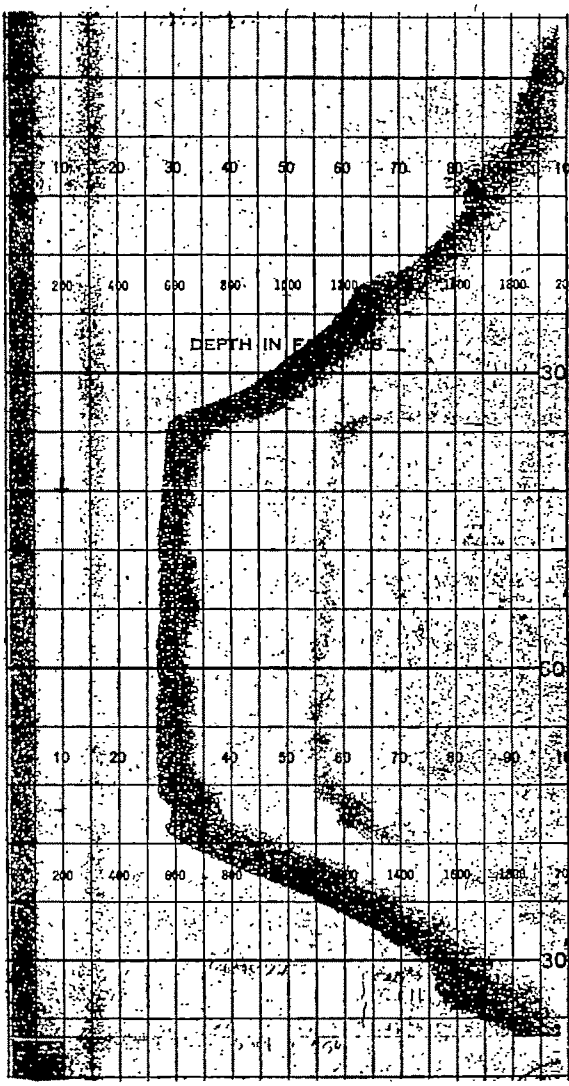

Fig. 8. Fathometer recorder trace of guyot in latitude 14° 20′ N., longitude 165° 55′ W. Ship's speed, 18.7 knots; course 059° true.

lagoon, unless it were filled in with younger sediments. On an atoll, the profile breaks abruptly outside of the living reef and descends in slopes averaging about 25°. There is no feature

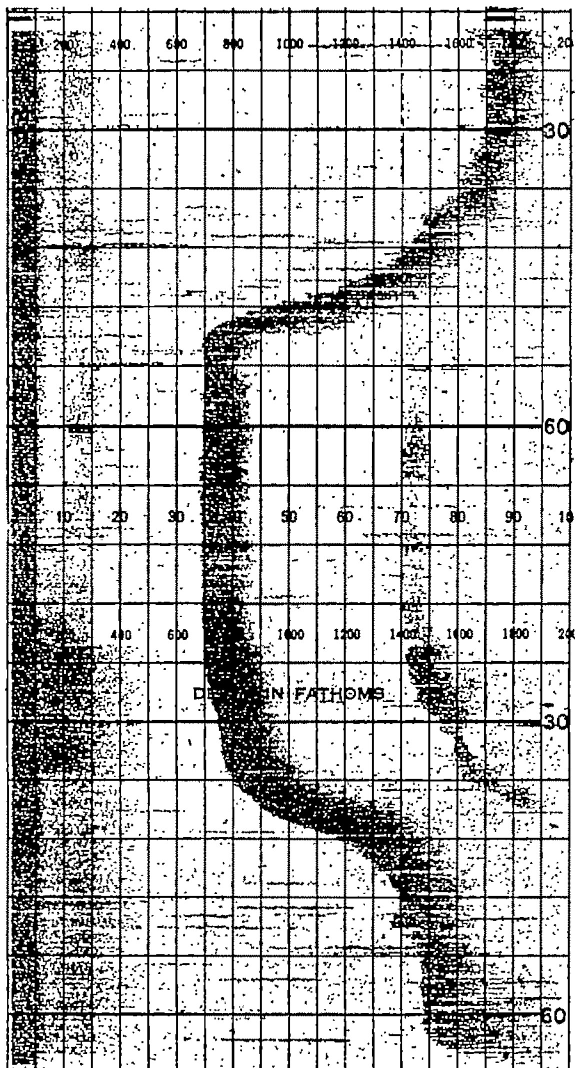

Fig. 8B. Fathometer recorder trace of guyot near latitude 21° N., longitude 178° E. Ship's speed 18.5 knots, course 059° true.

comparable to the gently sloping shelf found around the flat tops of nearly all guyots. In fact there seems to be no way of accounting for these shelves unless the guyots had developed in a sea which did not support reef-building organisms.

It may reasonably be assumed that guyots were originally volcanic peaks. After a long period of time they became stabilized and were eroded down to low relief. At this time they developed gently sloping shelves around them as might be expected in the case of a maturely dissected island. This was followed by a long period of marine planation, unhampered by reef growth, ultimately forming the flat upper surfaces. If marine planation cut the island down to about 30 fathoms below sea level then the outer margin of the gently sloping shelves, normally some 70 fathoms deeper, would have originally represented approximately a 100-fathom-curve around the island.

Possibilities of accounting for the reef-free surface of the guyots by some connection with a glacial epoch were considered and rejected. If reef growth had been inhibited by a glacial epoch, the guyots would have had to have suffered marine planation followed by sudden subsidence to below the level at which reef growth would recommence at the end of the glacial epoch—a coincidence which makes the hypothesis very unlikely. The glacial epoch would have had to be a very long one to permit complete planation of the larger guyots. It cannot possibly be referred to the Pleistocene epoch since the Marshall Islands atolls are younger than the guyots and there could obviously not have been time for marine planation, subsidence and upbuilding of the atolls all in this short epoch aside from the inconsistency that the cold water was called upon to keep the guyot surface reef-free but later on permitted the upbuilding of the atolls.

GENERAL RELATIONS WITHIN PACIFIC BASIN.

Since it is difficult to discuss any theory of origin of guyots against the background of misconception and ill-founded theories which at present confound geologic literature on ocean basins and the Pacific Basin in particular, the writer proposes to wipe the slate clean and start on a new basis.

The Pacific Basin is here considered to comprise the central portion of the ocean and is bounded by an almost continuous belt of strong late Cretaceous-Tertiary mountain building. On the northern and western borders this belt is characterized by elongate deeps which lie over downbuckles of the Earth's Crust.[2] Related island arcs show intense volcanic and seismic

[2] See the works of Vening Meinesz and others on gravity at sea.

activity.[3] On the eastern margin are found the cordilleras of the North and South American west coasts and on the south little known Antarctica. The volcanic rocks of the islands of the Pacific Basin are dominantly basaltic whereas those related to the island arcs and their uplifted cordillera equivalents are dominantly andesitic. The area of arcs and cordilleras bordering the Basin is tectonically the most active and unstable area of the Earth's Crust today. The Pacific Basin itself seems to be tectonically a most stable area and possibly has been throughout geologic time.[4] One encounters no evidence of folding anywhere over its broad expanse. Though fault scarps can be found their rarity bespeaks great stability. Seismic activity in the Pacific Basin is almost nil.

The writer favors Buddington's (1943) concept of the nature of the Earth's Crust and considers that the suboceanic crust probably consists of horizontally layered rocks including such types as norite, gabbro, anorthosite, pyroxenite, peridotite, dunite and probably some eclogitic facies. These are relatively strong rocks. Stronger than the granitic to quartz dioritic rocks which presumably make up the "granitic" layer of continents. The writer believes the oceanic crust is very strong though this opinion is at variance with existing textbooks and much of the current literature. However, Jeffreys (1929), Daly (1940), and Longwell (1945) all favor a strong oceanic crust. The only bases for judging its strength are its

[3] There is general agreement as to the position of the "andesite line" along the western margin of the Pacific Basin except for the area of the Carolina Islands. Some place these inside and some outside of the "andesite line." The writer tentatively includes most of the Carolines in the Pacific Basin and traces the "andesite line" down their western margin including Ulithi, Yap, Ngulu and the Palaus behind—on the west side of—the "andesite line." This is essentially the same as the line drawn by Hobbs (1944).

[4] Having obtained considerable first-hand information in the Pacific during the past few years the writer must now revise the views expressed in Betz and Hess (1942). The tentative trend lines shown on the chart should be considerably reduced in number by eliminating practically all of northeasterly trends. Further development of the bottom topography shows that they do not exist. The hypothesis that certain linear groups of islands and shoals, particularly the Hawaiian group, lie along a major Earth fracture which may be a strike-slip fault is retained. The relationship on a small scale of the volcanic activity to fractures has been demonstrated by Stearns and MacDonald in Samoa and Hawaii. The trends of these fractures are approximately parallel to the elongation of Samoa and the elongation of the Hawaiian chain.

behavior and the strength of the rocks of which it is thought to be composed. Both of these indicate strength. The reason it has been generally considered to be weak, appears to be related to calling it the exposed sima or the basaltic substratum and consciously or unconsciously bringing in Daly's theory of a weak glassy basaltic substratum. But Daly postulated a strong crust and weak substratum at considerable depth. Those favoring the hypothesis of continental drift assumed a very weak basaltic crust below the oceans without, so far as the writer is aware, presenting evidence other than the hypothesis of drift to substantiate the assumption.

Many authors have correlated the observation that island arcs (and hence mountain building) develop in the ocean basins along the margins of continents with the concept that the continental massifs are strong and the oceanic crust weak thereby accounting for the localization. However, if mountain building forces are related to convection currents within the Earth (Griggs 1939), the most satisfactory of the present theories, then the localization can more reasonably be explained on the basis of heat relations within the crust. Being warmer under continents and cooler under oceans the downward flow part of the convection cell would be more likely to be localized under the ocean and would be supplemented in some cases by the outward flow of warm material from beneath the continental area.

Having concluded that the Pacific Basin was in general strong and stable, it is now appropriate to turn to exceptions in detail to these generalities. All volcanic islands of the ocean basin proper (excluding from this discussion the highly unstable island arc areas) are subject to frequent vertical movements as long as vulcanism is active. In this sense they are unstable. The expansion during magma generation, injection of magma into the crust below the volcano, crystallization of magma and contraction, extrusion of magma from a central vent and isostatic adjustments to the load, out-flow of weak oceanic clays from beneath the volcanic load, etc., all tend to result in vertical movements of the volcanic island. Such islands may have terraces extending to hundreds of feet above sea level and at the same time have drowned shore lines and exhibit a series of submerged terraces as well. Once this vulcanism dies the island will probably become stable. Of the hundreds of atolls and banks with their volcanic pedestals beneath

them, one can find very few in the Pacific Basin which have had their coral reefs uplifted by as much as 150 feet.[5]

Aside from vulcanism and its effect of producing local points of instability, convection currents of lesser intensity than those producing island arcs may result in vertical movements of the suboceanic crust at times.

HYPOTHETICAL DEVELOPMENT OF THE HISTORY OF THE PACIFIC BASIN AND THE ORIGIN OF GUYOTS.

Most discussions of Pacific historical geology jam all the known history into the late Tertiary, Pleistocene and Recent ages. To be sure the rocks visible on the surface of volcanic islands are mostly very young, predominantly Recent plus some Pleistocene and very rarely rocks that can be demonstrated to be as old as Tertiary. Many writers seem inclined to place Pacific atoll formation in the Pleistocene though others extend it back into the Tertiary (Stearns 1946). On the other hand the Pacific Basin is generally considered to be very old, probably dating from early Pre-Cambrian time (Kuenen 1937). It seems reasonable to suppose that volcanic activity in the Pacific Basin and hence island formation has gone on sporadically since early Pre-Cambrian. Where then are the Pre-Cambrian, Paleozoic and Mesozoic islands? In order to answer this it is necessary to digress along several other channels.

Any island formed in the Basin can be assumed to have begun as a volcano or group of volcanoes. After vulcanism ceased and the island had become stabilized, the following sequence of events would necessarily take place. The island would be eroded to low relief, and after a long period of time (providing growth of reef-forming organisms did not interfere) the island would completely disappear as a result of marine planation. Such must have been the fate of all Pre-Cambrian islands before reef-forming organisms existed.

Kuenen (1937 and 1941) has concluded that there has been little change of sea level since early Pre-Cambrian time. He estimated that the rate of sedimentation in the deep sea is approximately 1 cm. in 10,000 years for red clay, since the

[5] Vening Meinesz (1941) re-examines gravity data for oceanic islands. Though large, local, positive, isostatic anomalies are found on such islands, the regional anomalies show that such small islands are regionally and not locally compensated and thus closely approach isostatic equilibrium. This indicates a geologically rapid adjustment to the disturbance of equilibrium brought about by vulcanism.

end of the Pre-Cambrian, and 1 cm. in 5000 years for globigerina ooze. Since most of the material deposited on the ocean floor has ultimately come from the continents, isostatic adjustment of the load on the sea floor and the loss of weight from the continents has resulted in the sinking of the former and rise of the latter so that relative sea level with respect to the continents has not changed very much. One obviously cannot put a layer of several thousand feet of sediments into the oceans without causing the water to rise by an equivalent amount (less the water included in pore space in the sediments). Thus, quite apart from the discussion of isostatic adjustment mentioned above, every centimeter of sediment put into the ocean causes sea level to rise with respect to an oceanic island by just a little less than a centimeter (less by the amount of water in pore space of the sediment). Even though the figure cited for the rate of sedimentation may be inaccurate it nevertheless follows that oceanic islands are and have always been slowly sinking relative to sea level.

It stands to reason that once lime-secreting organisms appeared in the oceans, presumably in Cambrian time they would grow upon any available shallow, wave-cut platform and both tend to protect it from further wave action and build it up to sea level. These reef-forming organisms need not have been very efficient reef builders to keep pace with a settling rate of 1 cm. in perhaps 5000 years. So that beginning in Cambrian time every island in warm seas which at that time had not been submerged below the level at which these organisms could live, would be built up to sea level or nearly to sea level and could henceforth maintain its growth. In other words all Paleozoic, Mesozoic and Tertiary islands which were eroded to low relief and submerged in warm seas must inevitably become banks or atolls and be maintained as such throughout the remainder of geologic time except for the interference of some rare diastrophic accident. Epochs of glaciation might inhibit growth of reef-forming organisms temporarily. But these epochs are too short to permit the islands to sink to such a level that growth would not recommence with the return of warmer water.

We may now turn to the ultimate objective of this long series of digressions, the guyots. It is proposed that they represent the relics of Pre-Cambrian islands formed by the processes suggested above. The group of guyots with which we have been mainly concerned range from 520 to 960 fathoms

(3120 to 5760 feet) below sea level. Accepting Kuenen's figures for accumulation of sediments at least 2000 feet of sediments (solid) would have been deposited in the deep sea since Pre-Cambrian time. The great bulk of sediments, however, are deposited along continental margins, on the shelves, slopes and shallow epeiric seas. It is almost impossible to estimate the amount of water displaced by these inasmuch as a thickness of tens of thousands of feet may displace only a relatively small amount of water since the bottom of such basins of sediments tend to sink isostatically under the load. These thick prisms of sediments may at a later time be deformed and welded to the continents, thereby enlarging the continents at the expense of the oceans. Certainly these processes have decreased the areal extent of the oceans a considerable if unpredictable amount since the end of the Pre-Cambrian. If sediments deposited in shallow waters around the continents displaced only half as much water as deep-sea sediments, an estimate which seems to the writer to be on the conservative side, then one could account for a rise of sea level relative to an oceanic island of 3000 feet (500 fathoms) since the end of the Pre-Cambrian which is comparable to the present depth of the shallowest guyots. Thus we might attribute most guyots to a Proterozoic episode of vulcanism. The occasional, less well-preserved surfaces mentioned in the text, having depths between 1100 and 1900 fathoms might be older and well back in the Pre-Cambrian in age.

RECOMMENDATION FOR FUTURE RESEARCH.

With above hypotheses in mind it would be exceedingly interesting to drill a hole 5000 feet deep in the center of a Pacific Basin atoll. It is necessary to avoid the outer margin of the atoll since it may well have built outward over its own debris. From another point of view, a hole drilled on the southern rim of Eniwetok would almost certainly penetrate into the underlying guyot at a depth of approximately 4200 feet. It would be extremely interesting also to make magnetic surveys of a number of atolls to estimate the depth to the volcanic core and perhaps couple such an investigation with seismic and gravimetric work. Bottom samples with the piggot sampler taken from the flat tops and gentle marginal slopes of guyots might bring up some of the rock of which they are formed, provided these surfaces had been swept completely clean of sediments. Pleistocene to Recent banks in high latitudes where

cold water would inhibit growth of reef-forming organisms should be investigated to compare their profiles with those of the guyots. A further investigation of Murray's seamounts in the Gulf of Alaska might furnish some of the missing clues to the origin of guyots, and might, if the hypothesis here presented is correct, show features exactly comparable to guyots but at depths shallower than 500 fathoms. At the latitude of the Gulf of Alaska the water may have been too cold for reefs to grow on the platforms.

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RELATIVE GROWTH IN A PHYLOGENETIC SERIES AND IN AN ONTOGENETIC SERIES OF ONE OF ITS MEMBERS.

STEPHEN W. GRAY.

ABSTRACT. Relative growth curves of the type $y=bx^k$ are presented for 24 species of ceratopsians and for an ontogenetic series of *Protoceratops*. A number of skull dimensions are compared phylogenetically and ontogenetically. The phylogeny revealed agrees with Lull's arrangement of the family. Certain dimensions show different values for b and k in different phyletic lines while others do not. The former may be considered as having diagnostic taxonomic value for units of less than family rank while the latter remain constant throughout the sub-order. One form (*Styracosaurus*) showed characteristics of two different phyletic lines depending upon whether the spines of the crest were included in the measurement of the crest or not. The highest value for k was found to be 1.96 for the distance between horn cores in relation to beak-orbit distance. Nasal horns show a negative value for k.

CHANGES in the proportions of the dimensions of the body are the most obvious differences between young and old animals and between animals of different species. Since Huxley (1) showed that in very many cases these changes in proportion follow the form of the equation $y=bx^k$ many excellent studies of ontogenetic series have been made. Phylogenetic material has been less used and little is yet known about the actual relation between phylogenetic and ontogenetic growth curves. Hersh (2) studied the phylogeny of titanotheres and showed that horn cores increased with the skull length according to the relative growth equation and that genetic mutations for increased total size could account for progressive enlargement of horns. Phleger (3) applied the method to a number of extinct felids and merycoidodontids and found close agreement between the phylogeny predicated by Thorpe for the latter and the curves of relative growth.

In the present paper an attempt is made to apply a similar relative growth analysis to the skulls of the late Cretaceous horned dinosaurs, the Ceratopsia. Material was available for a phylogenetic study of about two dozen related species and for an excellent ontogenetic series of one of them. The ceratopsians have been monographed by Hatcher, Marsh and Lull

(4) and by Lull (5). Brown and Schlaikjer (6) have described the ontogenetic series of *Protoceratops*.

Lull (5) constructed a phylogenetic tree of the larger Ceratopsia and placed the known forms in two phyletic lines as shown in Fig. 1. These lines will be designated as "long-crested" (*Chasmosaurus-Torosaurus* line) and "short-crested" (*Monoclonius-Triceratops* line). No attempt was made to fit *Protoceratops* into this tree largely because the Mongolian horizon from which it is known has not yet been correlated with the American series from which the larger ceratopsians have been recovered. To see if this form could be fitted to either of the American phyletic lines was one of the problems attempted in this paper.

MATERIALS AND METHODS.

The following dimensions for ten specimens of *Protoceratops* of different ages and for twenty-two species of American ceratopsians provided the material for the comparisons:

Median length of skull (beak to crest)
Center of orbit to posterior margin of crest
Center of orbit to beak
Antero-posterior diameter of orbit
Center of base of brow horn core to center of base of nasal horn core
Greatest width of crest
Width at quadrates
Depth of face
Basal length of skull (beak to occipital condyle)
Beak to center of base of nasal horn core
Center of base of brow horn core to posterior margin of crest
Height of nasal horn core (where present and intact)

In all cases of *Protoceratops* the authors' measurements were used. For many of the larger animals similar measurements were available in one or the other of the monographs cited above. Where this was not the case, measurements were taken from the photographs and drawings of the skulls. Where this was necessary an actual measurement from the skull was used to provide the proper scale. Only those dimensions which lay in the plane of the photograph were used. Because of these limitations all of the above measurements were not available for every species. Measurements were in millimeters but when

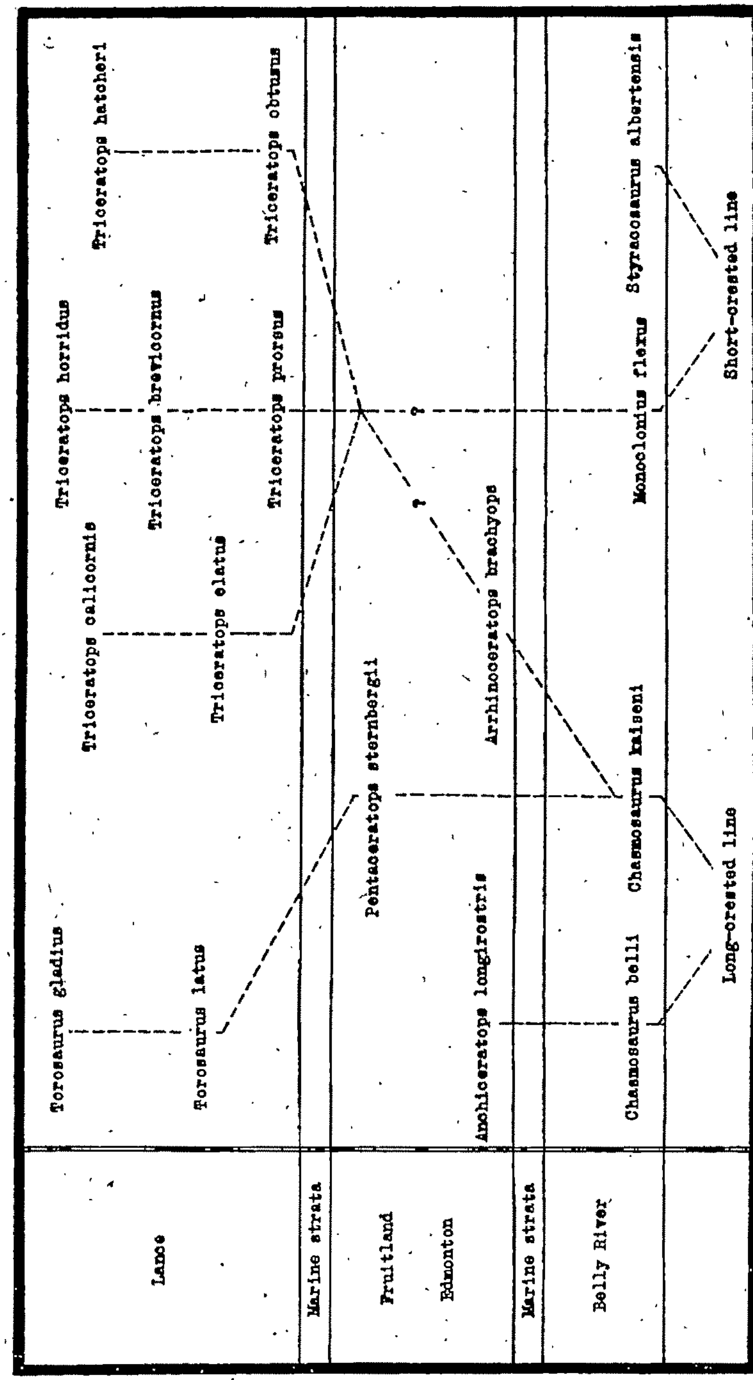

Fig. 1. Phylogenetic Tree of the Ceratopsia adapted from Lull (5).

converted to logarithms for plotting and computing values of b and k, only two significant decimal places were used. It was considered that this allowed for errors due to distortion and avoided the spurious accuracy which might appear from using logarithms with more places.

Data were plotted on double logarithmic scales and fitted to straight lines of the relative growth equation $y=bx^k$. Fitting was by the method of least squares, b and k being obtained arithmetically. The adult *Protoceratops* was not included in calculating the growth curves of either of the phylogenetic series because its position relative to the two lines was yet to be determined. Two other forms, *Brachyceratops* and *Triceratops obtusus* have also been plotted but left out of the calculations, the former because it is known not to be a mature animal, and the latter because it has been extensively restored.

RESULTS.

In every relative growth plot the *Protoceratops* data were easily distinguishable because of the small size of the animal. The phylogenetic data sorted itself into two distinct groups in the following plots:

- Median length of skull to orbit-crest distance (Figure 2A)
- Orbit-crest distance to orbit-beak distance (Figure 3B)
- Median length of skull to brow horn core-nasal horn core distance (Figure 2D)
- Brow horn core-nasal horn core distance to diameter of orbit (Figure 4A)
- Brow horn core-crest distance to brow horn core-nasal horn core distance (Figure 3A)

These two groups were nearly coincident with Lull's long-crested and short-crested phyletic lines.

In the second group of plots the two phyletic lines were less separated. The data fell into a more or less broad band instead of two diverging lines. One edge of the band was occupied by one phyletic line and the other edge by the other. The following plots were of this type:

- Median length of skull to orbit-beak distance (Figure 2B)
- Beak-orbit distance to diameter of orbit (Figure 3C)
- Orbit-crest distance to depth of face (not figured)
- Median length of skull to width of crest (Figure 4B)

The last of these relations showed a very narrow band, thus

connecting this series of plots with a third group in which there was no separation of the phyletic lines at all. Such plots were:

Brow horn core-nasal horn core distance to beak-orbit distance (Figure 2C)
Beak-orbit distance to depth of face (not figured)
Beak-nasal horn core distance to median length of skull (not figured)

The values of k and b in the relative growth equation are given in Table I. It should be noted that the dimensions are assigned to x or y arbitrarily. If x and y are reversed the value for k becomes its reciprocal.

Only where the two phyletic lines were separated are separate values for each line given. Obviously dimensions involving horn cores were not applicable to the hornless *Protoceratops* although in the fully adult animals there are slight thickenings at the positions occupied by horns in the later forms.

THE PHYLOGENETIC SERIES.

The agreement between the two phylogenetic groups and Lull's own hypothetical phylogeny is excellent. A few individual cases of differences must, however, be noted.

(1) *Chasmosaurus kaiseni.* This skull (AMNH 5401) in nearly all cases falls with the short-crested phyletic line rather than with the other members of the genus in the long-crested line. This is especially marked in the median length of skull to orbit-crest distance and median length of skull to orbit-beak distance relations. This is a less serious disagreement than it seems, for this species usually falls well down toward the crossing of the two lines and some cases may be said to lie at that point (Figure 2A). It is rarely far from *Monoclonius flexus* and thus the bifurcation of the two phyletic lines may be less remote than is postulated by Lull's diagram.

(2) *Arrhinoceratops.* Lull connects this form with the short-crested group by a dotted line and a question mark and says "it may prove to be ancestral to *Triceratops*." Nothing in this study bears out this hypothesis. In only one case (median length of skull to orbit-crest) is its position equivocal and there the deviation is not greater than would be expected from the methods of measurement.

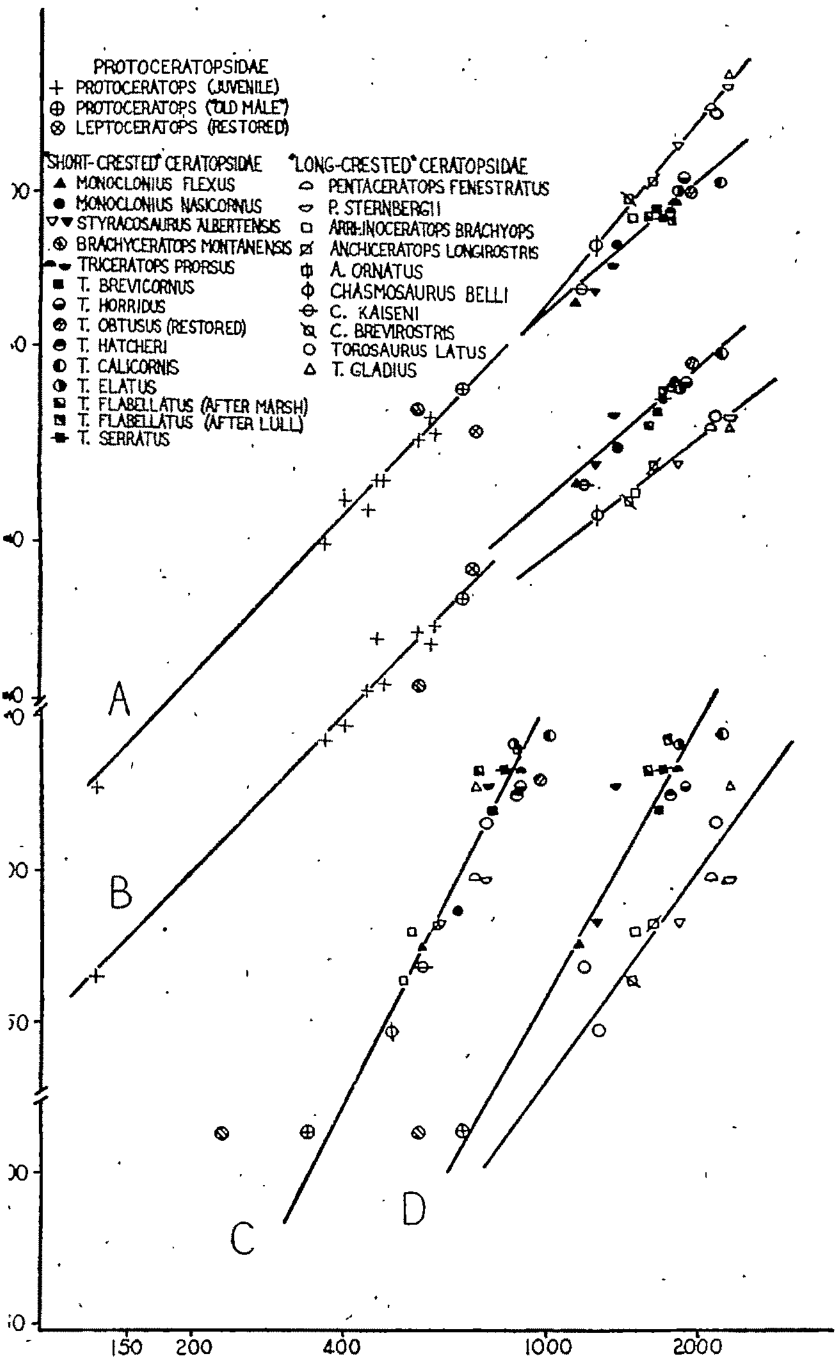

Fig. 2. Relative Growth Curves: A. Median length of skull to orbit-beak distance. B. Median length of skull to orbit-crest distance. C. Brow horn core-nasal horn core distance to beak-orbit distance. D. Median length of skull to brow horn core-nasal horn core distance.

The *Protoceratops* series (crosses) is ontogenetic, the other lines indicate the phylogenetic series. The first distance given is always the abscissa.

(3) *Styracosaurus.* This skull is provided with eight spines projecting from what appears to be the posterior margin of the crest. A line connecting the tops of these spines is continuous with the diverging lateral margins of the crest and concentric with the posterior margin. Superficially the problem appears to be: where is the crest margin? Shall the margin of the crest be taken as the base of the spines or the line connecting their tips? If the line connecting the spine tips is used to determine the median length of the skull, width of crest, and crest-orbit distance, the relative growth measurements involving these dimensions show the skull to fall into the long-crested phyletic line. If the same measurements are now taken to exclude the spines of the crest, a marked reduction of total length, crest length and crest width results and in relations involving these dimensions, *Styracosaurus* falls in the short-crested line where Lull placed it. In other words this skull shows both long-crested and short-crested growth patterns and it is not impossible that it represents a position near the divergence of the two lines in which one pattern has not completely surrendered to the other. In relations not involving crest dimensions, the skull fits into the long-crested group (Figure 3C and Figure 4A). Both positions have been plotted where the crest dimensions are involved (Figure 2A, 2B, Figure 3A, 3B).

(4) *Anchiceratops longirostris.* Crest width in this skull is considerably less than is to be expected, Figure 4B. This is not due to unusual length but to failure of the posterior portion of the crest to expand as in other forms. The typical wedge shaped form ceases posterior to the level of anterior lateral process of the squamosal and the lateral margins of the crest parallel one another instead of continuing to diverge posteriorly.

(5) *Triceratops obtusus.* This form has been restored on paper by Lull, (5) p. 126. Measurements from this restoration show that the dimensions agree well with the growth curve for the short-crested forms and that so far as the dimensions studied are involved, the restoration is probably correct.

(6) *Triceratops flabellatus.* Both the 1904 paper reconstruction by Marsh (4) and the actual reconstruction in 1934 by Lull (9) have been measured. While there are differences between the two it will be seen that the position of this species in the short-crested line is not greatly altered.

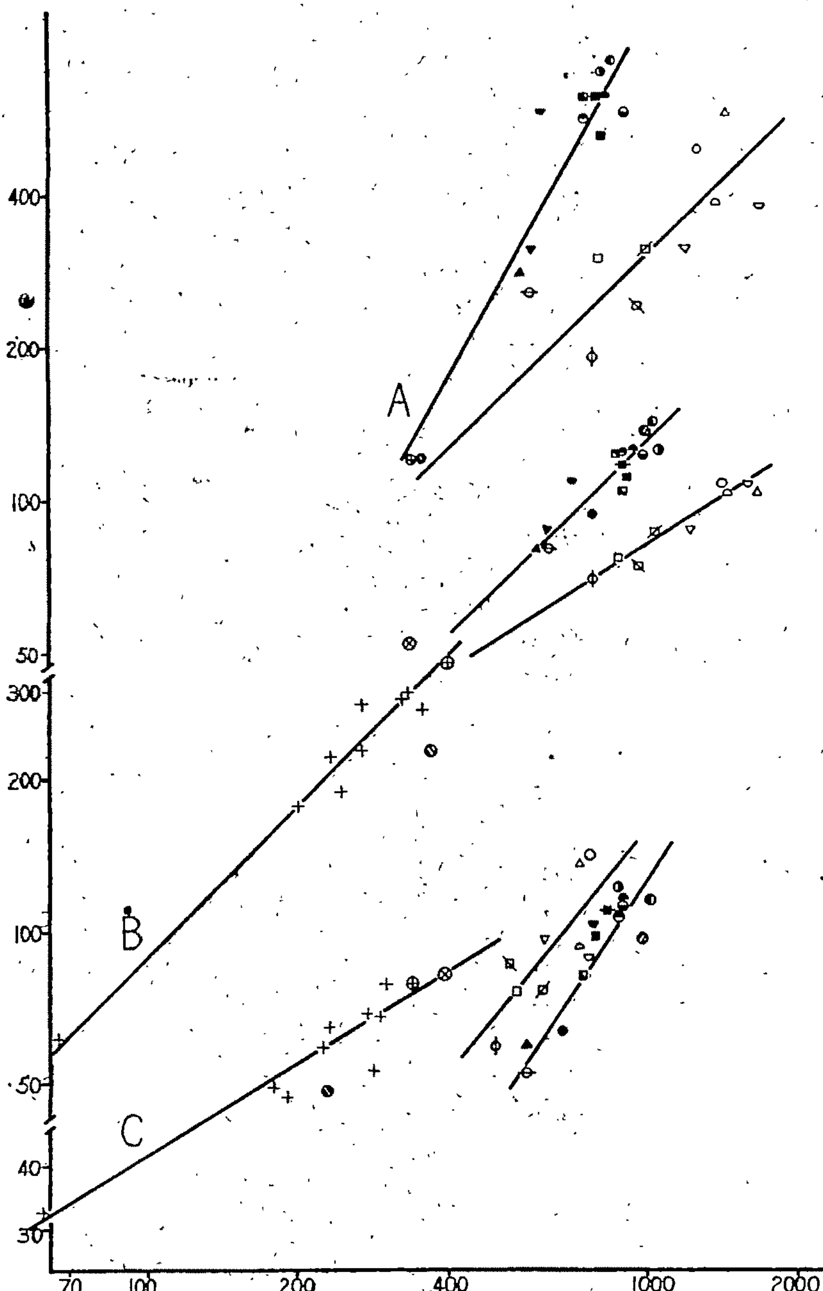

Fig. 8. Relative Growth Curves: A. Crest-brow horn core distance to brow horn core-nasal horn core distance. B. Orbit-crest distance to orbit-beak distance. C. Beak-orbit distance to diameter of orbit. Symbols as in Fig. 2.

(7) *Leptoceratops cerorhynchus.* This skull was extensively restored by Brown and Schlaikjer (10) and some dimensions of this restoration have been plotted. It lies not far from the largest of the *Protoceratops* series and does not seem to lie clearly in either of the phyletic lines of the larger forms. Its relation to *Protoceratops* is clear but the reconstruction necessary makes it of questionable value for relative growth measurement.

THE ONTOGENETIC SERIES.

The *Protoceratops* material falls into a single line with no more deviation than is to be expected due to possible distortion. The data come from a mixed group of males and females according to Brown and Schlaikjer (6). As these authors believe they can distinguish the sexes, the possibility exists that two different curves might result from considering them separately. There were not enough measurements provided to test this. No indication is found in any of the curves that there is any change in the slope of the line in the range represented. It is known that relative growth curves may fail to fit the empirical equation at very small sizes. But as the smallest individual has a skull length of 130 mm. which cannot be more than five times its length at time of hatching, it would seem that the curve must deviate but little from the straight line.

The position of *Protoceratops* in relation to either of the phyletic lines of the American ceratopsians is not clear. In most cases the adult skull of the series lies close to the point of divergence of the lines, sometimes nearer one line and sometimes the other. In many of the relations between dimensions it could be fitted to either phyletic line without much distortion. In certain instances, however, it does not lie near the extrapolation of either. This is true in median length of skull to width of crest, beak-orbit distance to brow horn core to nasal horn core distance, median length of skull to depth of face, and all instances where orbit diameter is involved. Marked change in relative growth rates must have taken place if *Protoceratops* is ancestral to the larger ceratopsians. In all probability, it is not directly ancestral and where its position on the relative growth curves does not fit with the American forms it may be assumed to indicate divergence from the line leading to the later

forms. However its relationships are to be considered, new and different growth rates for certain of its dimensions would be necessary to bring it into harmony with the other forms.

In only one case (median length of skull to orbit-crest, Figure 2A) does the line appear nearly identical in b and k with either of the phyletic lines. That the agreement is not more often found is not surprising. Little is definitely known about the relation of ontogenetic to phylogenetic growth curves but there is little reason to believe that they need coincide. It is not probable that the ontogenetic curves for other ceratopsians would show better agreement but more likely that they would roughly parallel the *Protoceratops* line, intersecting the phyletic line at the position of the adult individual. This is further emphasized by the fact that the immature *Brachyceratops* frequently falls far from either phyletic line, indicating that its position could only be known by at least one other example of a different age. By means of two known points one could attempt to predict the position of the adult animal.

DISCUSSION.

Both Hersh (2) and Phleger (3) felt that in their material a definite b and k should exist for each genus. Whether this is true for the Ceratopsia is unknown. The growth curves for each phyletic line may be the means for series of similar but slightly different curves for each genus included in the line. The small number of species in each genus renders this impossible to determine. That the two species of *Pentaceratops* from the Fruitland and Kirtland formation frequently lie in the same portion of the curves as *Torosaurus* from the later Lance formation would lead one to suspect that at least two parallel and perhaps coincident lines exist with one developing faster in geological time than the other. Further evidence of the possibility of concealed growth relationships is found when beak length and nasal horn core length are plotted against total length. No definable series are found and it is to be presumed that while a constant rate existed within each genus yet the representation does not provide enough examples to make it apparent. Characters such as these may be considered as having less than generic validity while others such as crest length have greater value.

It should be noticed that only certain dimensions show differ-

ences between long-crested and short-crested forms. Where no difference is apparent, as in the curves for median length of skull to width of crest and beak-orbit distance to brow horn core-nasal horn core distance, it is probably due to actual lack of difference, not to the quality of the data. In general it should be noted that the greatest differences in slope of growth curves are found in comparisons involving length of the crest. Smaller differences are found anteriorly. This does not mean that there is less variation anteriorly but that there is a single rate of change in the anterior portion while there are two different rates in the posterior portion of the skull. Where the growth curves of the two phyletic lines are neither identical nor widely separated, a banding effect occurs with segregation of each phyletic line to one side of the band. Some overlap may occur (Figure 2C, Figure 3C and 4B). This was frequently found by Hersh (2) in the titanotheres.

Although most of the data conform to the calculated lines there are probably certain breaks, the existence of which is implied. Such breaks in growth rates have usually been taken to be the result of genetic mutation. One discontinuity may be observed in the curves involving the diameter of the orbit. This is absolutely larger in the adult *Protoceratops* and has a lower rate of growth than in later forms of twice the size. Another possible location of a change in slope is found in the case of the narrow crest of *Anchiceratops longirostris* (Figure 4B). Although no descendant forms are known it seems probable that if they existed, they would show a new skull length to crest width relation with a value of k much lower than in either of the other phyletic lines. Still a third indication of the beginning of a new growth rate is the anterior position of the nasal horn core in *Triceratops flabellatus*. This has resulted in an increase in the brow horn core-nasal horn core distance, and a decrease in the nasal horn core-beak distance. The orbit-beak distance has not altered nor have any other proportions. Figure 4A shows that this skull deviates considerably from the related forms. Figure 2C shows that this deviation is less in the beak-orbit distance to orbit diameter and therefore it is only the position of the nasal horn that is changed while the other dimensions are unaltered.

Due to the deepening face of the animal both posterior (crest-orbit distance) and anterior (orbit-beak distance) halves

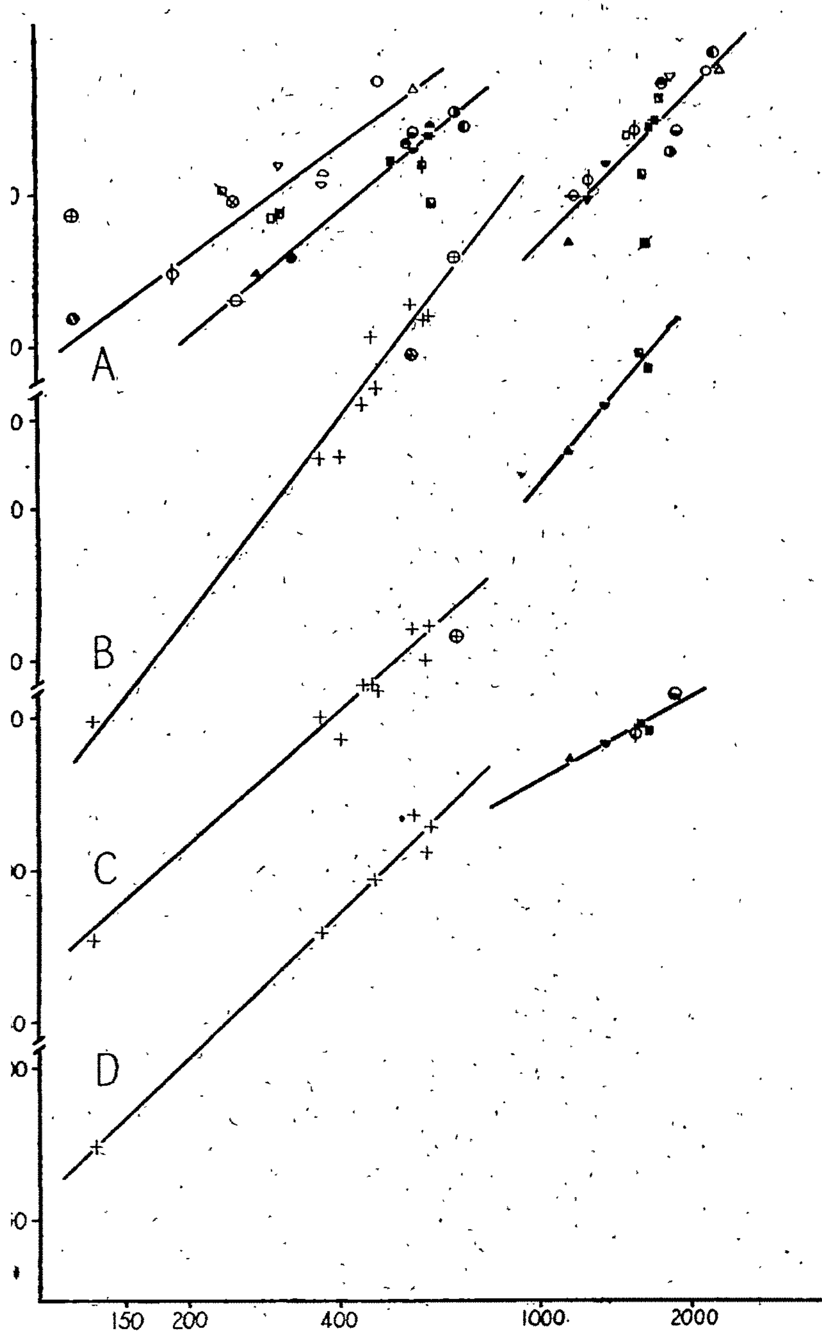

Fig. 4. Relative Growth Curves: A. Brow horn core-nasal horn core distance to diameter of orbit. B. Median length of skull to width of crest. C. Median length of skull to basal length of skull. D. Median length of skull to width at quadrates. Symbols as in Fig. 2.

appear to grow faster than the total length which forms the hypotenuse of the triangle. In *Protoceratops* the posterior portion is growing at a faster rate (k=1.050) than the anterior portion (k=1.019). In the long-crested branch this difference is much more marked (k=1.217 for posterior and 0.760 for anterior half). In the short-crested branch the difference remains about as in *Protoceratops* and the upcurving of the crest has brought the orbit back into the line between the beak and crest.

While the width of the crest increases as fast or faster than the length of the skull, the width at the quadrates decreases in rate of growth. This may be correlated with the fact that increase in diameter of the throat need not be linear with size of the animal.

The highest values for k are found for the distance between brow and nasal horn cores. In relation to the beak-orbit distance k reaches nearly 2 (Figure 8A) which indicates a correspondingly low k for the beak-nasal horn core distance. Why this separation of horn cores increases is not clear but it may be a further expression of the high phylogenetic growth rate of the brow horns themselves. It may also have enabled the beak of the animal to stay far enough in front of the forward slanting brow horns that the latter would not interfere with feeding!

Since the growth rate of the crest length with respect to the total length of the skull is within reasonable limits it may be assumed that the crest of *Protoceratops* was well developed at hatching. This assumption is further supported by the fact that the exposed region of the spinal cord between the foramen magnum and the neural canal of the axis needs protection in the young as well as the adult (Tait and Brown) (7). On the other hand caution in this interpretation is indicated by the work of Thompson (8) who showed that the rostrum of *Polyodon spathula* has a value of k=0.7 with respect to body length for lengths between 100 and 1500 mm. k increases, however, to 4.0 at a body length of 17 mm. and presumably the rostrum does not appear at all in the young of less than 10 mm. in length.

Similar considerations apply to the problem of the primitive ceratopsians. The low k values indicate that the crest could have appeared early in the phylogeny and in even the smallest

forms. This is contrary to the condition found by Hersh (2) with respect to titanothere horn cores where it is obvious that horns could not appear at all before a certain size was reached.

Mentioned earlier was the relation of orbit diameter to other skull measurements. Orbit diameter in relation to length of crest shows $k=0.592$ in *Protoceratops*. Such a low k is to be expected as no great increase in eye size with total size seems necessary. In the larger ceratopsians, however, k rises to 0.794 in the long-crested and to 1.330 in short-crested forms. This relatively high value indicates not a disproportionately large eye in large animals but a relatively small eye in small animals. Thus in *Chasmosaurus kaiseni*; with a median skull length of 1200 mm. the orbit is 62 mm. while in a not yet full-grown *Protoceratops* the orbit is 63 mm. when the skull is but 470 mm. in length. What factors are involved in these proportions is not clear. Even assuming that the relatively large eye of *Protoceratops* represented an adaptation for nocturnal or crepuscular habits there is still no way of accounting for the steep slope of the orbit diameter of the later forms.

Ceratopsian horn cores indicate that nasal horns appeared earliest and were for a time larger than the slightly later appearing brow horns. Subsequent regression of the nasal horn was accompanied by increased development of the brow horn. It was impossible to determine the growth rate of the brow horns as they are frequently broken and their length is problematical. An attempt to plot the height of the nasal horn cores against skull length for the forms where the horn core seemed intact showed merely that regression was of the order $k=-9.0$. This is an example of the type of growth described as "hyperbolic" by Hersh (2) who found a similar value for k in the free length of nasals in titanotheres.

CONCLUSIONS.

Phylogenetic relative growth curves of the general form $y=bx^k$ have been drawn for the skull dimensions for 24 species of ceratopsian dinosaurs. Ontogenetic curves for the same dimensions have been drawn for one of the species of the series (*Protoceratops andrewsi*).

With minor exceptions the relative growth curves agree with the phylogeny of the group as described by Lull.

Different phyletic lines show different values for k in the relative growth equations in only certain dimensions. Other dimensions show no such difference. This distinguishes characters which are constant for small taxonomic units from those which are constant for larger ones.

TABLE I.

Skull Dimensions		*Protoceratops*		Ceratopsidae Long-crested line		Ceratopsidae Short-crested line	
x	y	k	b	k	b	k	b
Orbit to crest distance	Beak to orbit distance	0.976	1.023	0.604	9.016	0.986	1.445
Median length of skull	Orbit to crest distance	1.050	0.417	1.217	0.129	0.872	1.849
Median length of skull	Beak to orbit distance	1.019	0.447	0.760	2.138	0.866	1.318
Median length of skull	Brow h.c. to nasal h.c.			1.371	0.0115	1.767	0.00111
Crest to brow h.c. distance	Brow h.c. to nasal h.c.			0.974	0.363	1.775	0.00417
Brow h. c. to nasal h.c.	Orbit diameter			0.720	1.622	0.805	0.724
Beak to orbit distance	Orbit diameter	0.604	2.680	1.200	0.0468	1.491	0.00508
Orbit to crest distance	Orbit diameter	0.592	2.570	0.794	0.389	1.380	0.0136
Median length of skull	Depth of face	1.196	0.0955	1.290	0.0178		
				Phyletic lines not separated			
				k	b		
Median length of skull	Basal length of skull	0.869	1.122	1.126	0.240		
Median length of skull	Width of crest	1.266	0.151	0.993	0.676		
Median length of skull	Width of quadrates	0.936	0.741	0.539	8.710		
Median length of skull	Orbit diameter	0.636	1.413	0.920	0.115		
Beak to orbit distance	Brow h.c. to nasal h.c.			1.963	0.001047		
Median length of skull	Height nasal h.c.			about −9.0			

No constant relation between the values for k in the ontogenetic and phylogenetic series was observed.

Unusually high rates of growth exist in the distance between nasal and brow horn cores and probably in height of brow horn cores. Negative relative growth is observed in height of nasal horn cores.

One form (*Styracosaurus*) showed characteristics of two different phyletic lines depending upon whether the spines of the crest were included in the measurement of the crest or not.

Restorations in the case of *Triceratops flabellatus* and *T. obtusus* show excellent agreement with the expected proportions.

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URBANA, ILLINOIS.

OBITUARY.

RUDOLF KAUFMANN.

News has been received of the death of Rudolf Kaufmann at the hands of Nazi soldiers some time between 1941 and 1944. In him our science has lost one of its most promising students.

Rudolf Kaufmann will be best remembered by his fundamental research on the evolution of *Olenus* in the Upper Cambrian of Sweden and the island of Bornholm. These beds are characterized by numerous species of that genus, each distinctive of its own biozone. With immense care Kaufmann collected a large material of cranidia and pygidia from carefully selected beds, usually not more than 8 cm. apart and, with the help of a specially constructed device, measured the proportions of a number of comparatively easily recognizable features. He found that each species possesses a number of features that are constant and others that are variable. The latter command considerable interest, because it was shown that these variable features undergo certain directional modifications during the geological history of each species and that, surprisingly, the trend of these modifications is more or less identical in successive species, that is, it is usually the same set of features which is being modified in the same way. Kaufmann called this process "Artabwandlung," an admirably short and precise term for which the writer is elsewhere proposing the unavoidably more cumbersome term "intraspecific directional modification." Intraspecific modification anticipates (in the earlier species) and repeats (in the later species) the phylogenetic evolution of the genus.

Unfortunately Kaufmann's papers were published in German periodicals with a limited publication abroad. They make worthwhile reading for everybody interested in evolutionary palaeontology.

Rudolf Kaufmann was born in East Prussia in 1908. The infinite variety of boulders of northern origin in the Pleistocene drift of northern Germany provides the budding geologist with a field museum of extraordinary dimensions which was Kaufmann's playground since early childhood. Play developed into serious work and soon Kaufmann studied at Königsberg, Munich, and finally at Greifswald under Bubnoff. When he left the university his training was comprehensive and his knowledge unusually wide for a man of his age. He never lost his interest in drift boulders to which one of his first publications was devoted. But gradually he went farther afield. His evolutionary studies have already been

mentioned. As a by-product of his field work in Scandinavia there appeared a study of the joint system of the Palaeozoic sediments in southeastern Sweden. He was familiar with granite tectonics and petrofabric studies and applied his knowledge to the study of the tectonics and mechanism of intrusion of the Bornholm granite. Only a preliminary account of the results was published. The main paper was later suppressed and is now presumably lost.

Thus the background was set for a splendid career when catastrophe came in 1933, shortly after Kaufmann's graduation from Greifswald University. Of Jewish descent, though Christian in second generation, he was now a "non-Aryan." A position in Germany was out of the question, Jewish organizations washed their hands, scientific emergency committees found that young men "without experience" were not wanted abroad. Desperately he tried to commercialize one of his many hobbies—he was an accomplished photographer and a certified teacher in sports and athletics,— first in Denmark, then in Italy and Danzig, finally back in Germany as teacher in a Jewish school. There followed years of prison and hard labour which his remarkable constitution enabled him to survive. From prison he maintained a scientific correspondence with friends abroad. Genetic problems and their application to palaeontology were closest to his heart and a manuscript began to take shape, full of interesting suggestions and possibilities, but now lost forever. An Australian visa was waiting, but all efforts to obtain his release were in vain. In the general confusion following the outbreak of war in September, 1939, he managed somehow to make his escape to Lithuania, only to find that the country to which he longed to go had closed its doors—he found that he was now a "German of military age."

After months of uncertainty and suspense he was allowed to settle down in Lithuania and once more he returned to geological work. When Lithuania was incorporated in the U.S.S.R. in 1940 he was finally appointed to the staff of the Geological Survey at Kaunas and with characteristic zeal he at once attacked problems of the Pleistocene drift with modern methods.

After the German invasion of Lithuania in 1941 Kaufmann continued his field work for some time, until one unlucky day two Nazi soldiers recognized him on a country road as the "Jew Kaufmann from Königsberg," took him away and murdered him.

Those who knew Rudolf Kaufmann will remember him as a cheerful companion, an indefatigable worker, and a sincere and mature scientist. He shared the fate of millions and his senseless death stands as a monument to human wickedness and ignorance alike.

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CURT TEICHERT.

SCIENTIFIC INTELLIGENCE

Chemistry.

Currents In Biochemical Research; edited by David E. Green. Pp. viii, 486. New York, 1946. (Interscience Publ., Inc., $5.00).—This book is a very interesting series of "thirty-one essays charting the present course of Biochemical Research and considering the intimate relationship of biochemistry to medicine, agriculture and social problems." The attempt has been made to write the essays in as simple language as possible consistent with sound scholarship, and on the whole this attempt has been rather successful. However, the difficulties in this direction can be appreciated if one attempts to translate the following sentence (page 199) into a form readily intelligible to a reader with no medical background. "The supraoptic nucleus governs secretion of the antidiuretic hormone of the neurohypophysis and section of the supraoptic neurohypophysial fibers is followed by insipid polyuria."

The thirty-three authors are active researchers and authorities in their respective fields. The broad selection of topics gives one a reliable survey of the status of most of the fields of biochemistry at present under intensive investigation, and in many cases some indication of probable directions of future development. The scientific material is at some points leavened, so to speak, by a discussion of social implications.

The volume constitutes another step in the important process, fortunately at present rapidly gaining momentum, of summarizing the developments in various fields of natural science in an authoritative form which is at the same time sufficiently non-technical in language so that workers in other fields, or even in other branches of the same field, will have no great difficulty in following the argument. The accelerating rate of accumulation of important scientific results requires an ever increasing effort in this direction.

JULIAN M. STURTEVANT.

Geology.

Principes de Géologie; by P. Fourmarier. 2d Ed., revised and enlarged. Pp. 1212 (2 vols.); 674 figs., plates. Paris and Liége, 1944 (Masson & Cie.; H. Vaillant-Carmanne S.A.).—The first edition of Professor Fourmarier's impressive work, published in 1933, was reviewed at length in the American Journal of Science (vol. 28, 1934, pp. 392-394). It is still true that probably no European

text surpasses this one in comprehensiveness; the wide learning of its author is evident in the length, arrangement and content of the book.

In this second edition the text has been revised in accordance with the progress of geologic knowledge during the last decade, it has been enlarged by roughly 80 per cent as to both text and figures, and finally it has been rearranged to advantage. An index has been added and many of the new illustrations are three-dimensional, constituting a great improvement over their predecessors.

The principal changes in arrangement occur in the discussions of lithogenesis, structural geology, and the areal geology of the world —the latter a subject not found in any American text. Basically the general organization of the book remains as before, and runs in this order: kinds of rocks; the making of rocks; rock structures; areal geology of the world with emphasis on major structural features; physical geography (weather and climate; oceanography; geomorphology).

This arrangement is both comprehensive and interestingly different from that of most American texts. The American teacher of geology follows the uniformitarian principle. Usually he begins with present-day processes and shows how they explain the features displayed by the rocks. Thus the rocks are presented to the student within a framework that emphasizes the conditions controlling their formation. In *Principes de Géologie* the rocks are learned within a descriptive framework; not until the end of the book is reached does the reader get a full picture of the processes that made them.

Again, American teachers of elementary students like to treat historical geology in terms of the geologic column, reconstructing Earth history period by period. Professor Fourmarier prefers an areal or regional treatment, somewhat after the manner of Suess. This method is admirable for more advanced students, but most American teachers believe it is not well suited to the elementary level. The areal picture here presented is clear and concise, and would be so useful that it is regrettable that it has no counterpart in the English language.

In the field of cosmogony European texts are far behind the progress of knowledge and speculation. The 1933 edition of *Principes de Géologie* set forth only the Nebular Hypothesis. The present edition states that that hypothesis is still "generally accepted, at least in Europe," but presents briefly the original, 1901, version of the Planetesimal Hypothesis, and goes no further than to mention (by name only) the contribution proposed by Jeans in 1916. Professor Fourmarier would perform a real service for European geologists if he were to enlarge his treatment still further,

including the later ideas of Jeans and of Chamberlin, the various contributions of Jeffries (1924 and later), the suggestions of Russell (1935), and the recent work of Alfvén.

However, the geologic field is so large that no general work can hope to give full coverage to all parts of it. The present work is an excellent and useful reference work, and as such it deserves consideration by all American geologists.

RICHARD FOSTER FLINT.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Handbook of Meteorology; Edited by E. A. BERRY, JR., E. BOLLAY, and N. R. BEERS. Pp. ix, 1068; profusely illustrated. New York, 1946 (The McGraw-Hill Book Co., $7.50). *Meteorology with Marine Applications*; by WILLIAM L. DONN. Pp. xv, 465; 24 tables, profusely illustrated. New York, 1946 (The McGraw-Hill Book Co., $4.50).—Two books on meteorology, recently issued by the same publisher, are extremely different. One, a huge tome of 1068 pages, is so precise and exact that it is hard reading. The other, less than half as large, is so easy to read that in places it is inaccurate.

The first book, "Handbook of Meteorology," edited by three naval officers, Berry, Bollay, and Beers, consists of various articles with a length of anywhere from ten to 120 pages by twenty-two authors. It begins with 120 pages of tables and diagrams. Some of them are highly valuable, but others, such as a table of the melting points of metals, seem far removed from meteorology. Unfortunately, there is practically no text to explain the tables.

Another 120 pages on meteorological calculations is practically a pure mathematical treatise. Later sections are not quite so technical, although most are designed only for the mature expert. They deal with many aspects of the physics of the atmosphere, especially the origin of storms.

As a matter of general interest the reviewer was struck by the following quotation from the preface: "Perhaps greater coöperation is required among individuals and among nations in the practice of meteorology than in any other social effort of man. This is so, simply because even short-period forecasts often depend on synoptic data that are beyond the reach of the individual meteorologist or the individual nation."

This need for extremely broad coöperation is doubtless one reason for another condition to which two of the authors refer, namely, the incompleteness of our knowledge of the weather. According to H. J. Stewart of the California Institute of Technology "there does not

exist at the present time any complete and coherent theory of the general atmospheric circulation . . . (although) most of the details of the atmospheric motions are well understood."

C. G. Rossby of Chicago University speaks similarly: "The science of meteorology does not yet have a universally accepted, coherent picture of the mechanics of the general circulation of the atmosphere. This is partly because observational data from the upper atmosphere still are very incomplete, but at least as much because our theoretical tools for the analysis of atmospheric motions are inadequate. Meteorology, like physics, is a natural science and may indeed be regarded as a branch of the latter; but, whereas in ordinary laboratory physics it is always possible to set up an experiment, vary one factor at a time, and study the consequences, meteorologists have to contend with such variations as nature may offer, and these variations are seldom so clean-cut as to permit the establishment of well-defined relationships between cause and effect."

After this introduction Rossby presents a new and highly suggestive analysis of the circulation of the atmosphere. He conceives of the vertical circulation of the air as consisting of three closed circuits on each side of the equator. In the trade wind zone the air moves equatorward near the surface, upward near the equator, poleward at high levels, and down again in the tropical zone of high pressure. In the storm belt of middle latitudes the air moves in the opposite way, that is, away from the equator near the earth's surface, upward at the northern edge of this belt, equatorward at high levels, and then down again. Finally, around the poles, we have a circulation like that at low latitudes. In other words, if one could look from the west toward a vertical section of the atmosphere running north and south, he might see the air moving in three great whirls. The whirls near the equator and near the poles move anti-clockwise. The one in the middle moves clockwise. Storms, which are the main subject of this book, are formed in general where the central whirl impinges on the northern whirl.

One of the most interesting features of this comprehensive and valuable book is what it omits. Nowhere is there more than the most perfunctory discussion of the fluctuations which occur not merely from day to day, or season to season, but from year to year. The book illustrates the remarkable progress made by meteorology in recent decades along the line of analyzing the movements of the air. It adds practically nothing to our understanding of the reasons for periods of drought, such as those in the 1930s, or for other fluctuations such as the prolonged hot spell experienced in the United States in March, 1946. Meteorology, like other sciences, moves forward first on one leg and then on another. At the present

time the leg illustrated by this book is very far in advance of the other.

The second book, "Meteorology with Marine Applications," by W. L. Donn, is written very simply and clearly, and is admirable for exactly the purpose expressed in its title. It gives a general, and on the whole, reliable outline of the subject, and shows how the various meteorological principles apply to the mariner.

The chief criticism of the book is that in the attempt at simplification the author has gone so far that he sometimes gives a distinctly wrong impression. For example, on page 12 he says that the air is almost completely transparent to the sun's rays. He pays no attention to the fact that the shorter wave lengths are almost completely cut out by the air. At high levels they create the ozone layer by converting O_2 into O_3, and it is now recognized that this layer is of considerable importance meteorologically. Again, on page 29, he gives a table for the "lapse rate," that is, the average rate at which the air actually becomes cooler as one goes upward from the earth's surface. On page 32 he gives another and quite different table showing the "dry adiabatic rate." The amateur student receives from the text no hint as to why these two tables are so different. The *poor* student is likely to get them thoroughly confused. The *good* student will be much worse off because he will wonder what is the matter. Only on page 48 is there any hint that an explanation is needed.

Again on page 57 we are told that the oceans are the main source of atmospheric moisture, and that "this condition is as old as the atmosphere and the ocean themselves. Yet there has been no significant diminution of the volume of the seas nor increase in the water vapor of the air." To a geologist it would certainly seem that during the glacial period the volume of the ocean changed significantly. Water enough to raise the sea level perhaps 250 feet was then taken from the ocean and locked up in the form of ice. Such mistakes are due largely to the author's attempt to make this book easy to read. Many of them could be corrected by adding such words as "usually" or "almost." On the whole, however, the book is good.

ELLSWORTH HUNTINGTON.

Eight Years of Archeological Work in Southern Mexico, Outlined Story of Newly Discovered La Venta Culture, News Release from National Geographic Society.—"After four months of field work near San Lorenzo, Veracruz State, in southern Mexico on the third of a group of important centers of the La Venta culture, a joint archeological expedition of the National Geographic Society and the Smithsonian Institution has returned to Washingon.

"The expedition, led by Dr. Matthew W. Stirling, has brought to the United States a complete photographic record of the excavations and a quantity of small objects to be subjected to further study.

"The season's activities mark the conclusion of eight years of work by Dr. Stirling under the sponsorship of the two institutions. The inquiries began in 1939 with the uncovering of a colossal basalt sculpture in the form of a human head, near Tres Zapotes, a village in Veracruz State. The site proved to have been a ceremonial center, marked also by earthen mounds. One of the most important discoveries during the series of expeditions was made at Tres Zapotes in 1939: an inscribed stela bearing in Mayan characters the earliest recorded date, believed to be contemporary, so far brought to light in the Western Hemisphere. The date has been interpreted as 291 B. C. according to the Spinden correlation or 31 B. C., Thompson correlation.

"The following year Dr. Stirling and his associates began excavations at the site of La Venta, Tabasco, so rich in monuments and artifacts that it has given its name to the newly discovered culture. La Venta, unlike the other two ceremonial centers, was a place of burial for important personages among the La Venta people. From the graves the excavators have recovered large quantities of ornaments and other art objects of jade, rock crystal, and serpentine, as well as a great variety of baked clay figurines, many of them of high artistic value. These objects are now in the National Museum in Mexico City.

"The San Lorenzo site, worked in 1946, is the farthest inland of the three sites excavated. It lies about sixty miles from the Gulf of Mexico on the Rio Chiquito. It is also the most extensive of the centers, and there, apparently, the sculpture of the La Venta culture reached its highest development. The five colossal heads discovered are for the most part better made, better preserved, and bigger than those from the other locations. Some of the heads are nearly ten feet high and are estimated to weigh more than twenty tons.

"The eight years of study in southern Mexico indicate that the La Venta culture at Tres Zapotes started about A. D. 800 and lasted there until about A. D. 1,000. The La Venta and San Lorenzo sites apparently were developed later and abandoned earlier.

"The correlation of art forms and pottery types points to the probability that the La Venta culture was a forerunner of much of the culture of the Mayas, the Toltecs, and the Aztecs. It is even considered possible by Dr. Stirling that the La Venta peoples invented the calendar and number system for which the Mayas are usually given credit."

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HOW OLD IS THE COLORADO RIVER?

CHESTER R. LONGWELL.

ABSTRACT. Wide divergence of published views regarding the date at which the Colorado River acquired its present through-flowing course calls for critical appraisal of the known evidence. Stratigraphic evidence west of the Colorado Plateau is as follows:

(1) The Muddy Creek formation, which is the youngest known interior-basin deposit through which the river has cut, may be as old as Miocene. Earlier classification of the formation as Pliocene (?) rested on grounds that now seem to be invalid.

(2) The oldest known deposits of gravel and silt that can be ascribed to the Colorado River have yielded limb bones of a camel, which I once accepted as evidence of Pleistocene age. I am now informed that a date as early as Pliocene is not precluded.

Therefore the course of the river west of the Plateau may date from late Miocene or early Pliocene time. It is suggested that an earlier drainage in the Plateau area may have been diverted to the present course partly by volcanism, and partly by crustal disturbances during the great epeirogenic uplift of the region.

INTRODUCTION.

THE Colorado River, cutting its valley deeply into varied bedrock in three major geologic provinces, has provided unexcelled lithologic, structural, and geomorphic exhibits. These exhibits furnish critical evidence bearing on the geologic history of a vast region. However, one of the major unsolved problems of the region is the date of origin of the river itself as a through-flowing stream in its present course from the high continental interior to the Gulf of California (Fig. 1). Solution of this problem would throw a flood of light on regional Tertiary events and relationships that now are obscure.

Since Powell's first historic trip down the Colorado, more than 75 years ago, several field workers have published their concepts of the origin and development of the river. Among the first of these was C. E. Dutton, (1882), whose ideas are discussed in later parts of this paper. Two publications in recent

years may be cited as representing extreme divergence in views regarding the date at which the present Colorado drainage came into existence. Blackwelder suggested (1934)—as a

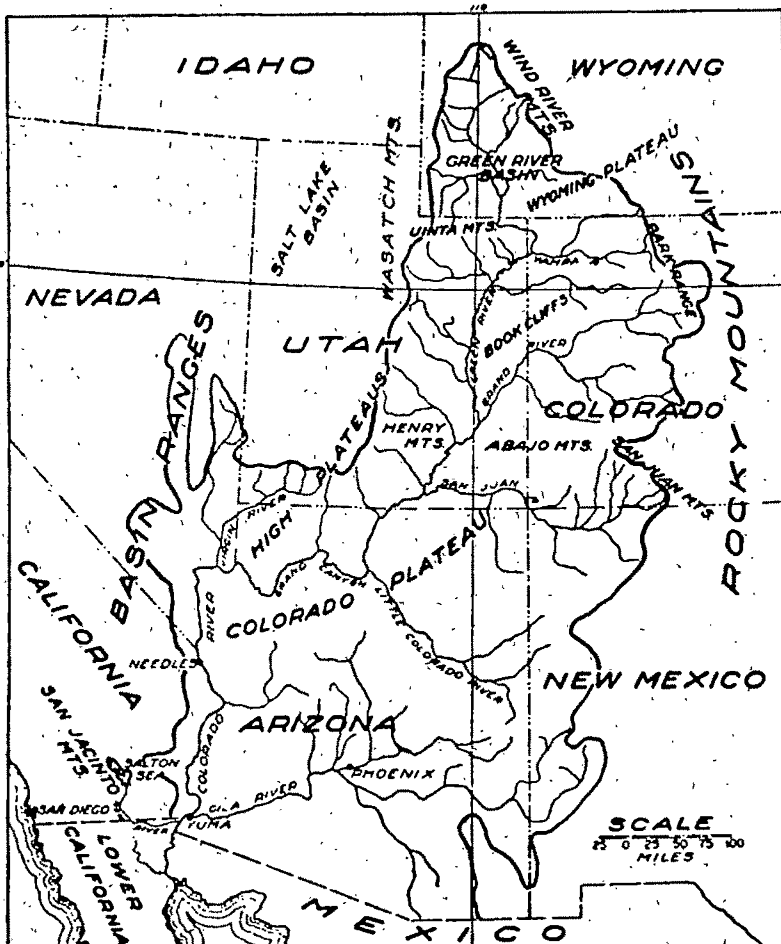


Fig. 1. Index map showing Colorado River and outline of its drainage basin; also, locations of principal topographic features mentioned in text. (After E. Blackwelder.)

frank hypothesis, seemingly in accord with admittedly insufficient data—that the Colorado as we know it resulted from integration of drainage in a number of arid interior basins, when, in late Pliocene and Pleistocene time, great regional uplift was an important cause of a more pluvial climate in the Rocky

Mountains and adjacent plateaus. According to this concept the river, as a channel for exterior drainage, "did not exist until about the beginning of Pleistocene time." More recently, Hunt (1946) has argued for the view that the Colorado River as an integrated drainage system dates from early Tertiary time. Geologists who have no direct acquaintance with the region will be at a loss to understand so wide a divergence in interpretation, and may welcome a studied summary of pertinent field evidence. I have a particular interest in undertaking such a review and appraisal because authors of the conflicting views have cited some of my own field work.

VIEWS OF EARLY WORKERS.

Dutton, who seems to have agreed essentially with Powell in his views regarding the history of the river, confined his attention exclusively to the part of the valley within the Colorado Plateau. To him the main events in the history appeared to be in clear and simple relation. During Paleozoic and Mesozoic times, the entire area was a sea floor, receiving sedimentary deposits. At the close of Cretaceous time, the region acquired a positive tendency. Irregular upwarping produced a series of wide basins that became fresh-water lakes, in which Eocene deposits such as the "Pink Cliffs formation" accumulated. With continued uplift, a drainage pattern of consequent streams must have formed. Once established, the positions of major valleys were essentially "immutable." Under a humid climate during all of early and middle Tertiary time, the rising land was under continuous attack by the Colorado and its tributaries, with the result that the thick formations from the Eocene to the "Permian" (meaning the Moenkopi formation, later determined to be of Lower Triassic age) were removed from a wide area. This period of erosion was Dutton's "Great Denudation," at the conclusion of which the Kaibab limestone, now at the rim of the Grand Canyon, floored a broad lowland flanked by subdued uplands on remnants of the younger rocks.

In late Tertiary time, according to Dutton, the regional climate became more arid, and widespread uplift occurred, attended by large-scale faulting and monoclinal folding. By this assumed dating of the East Kaibab monocline and related structural features, he sought to explain the anomalous behavior of the river in leaving an area of moderate altitude east of the

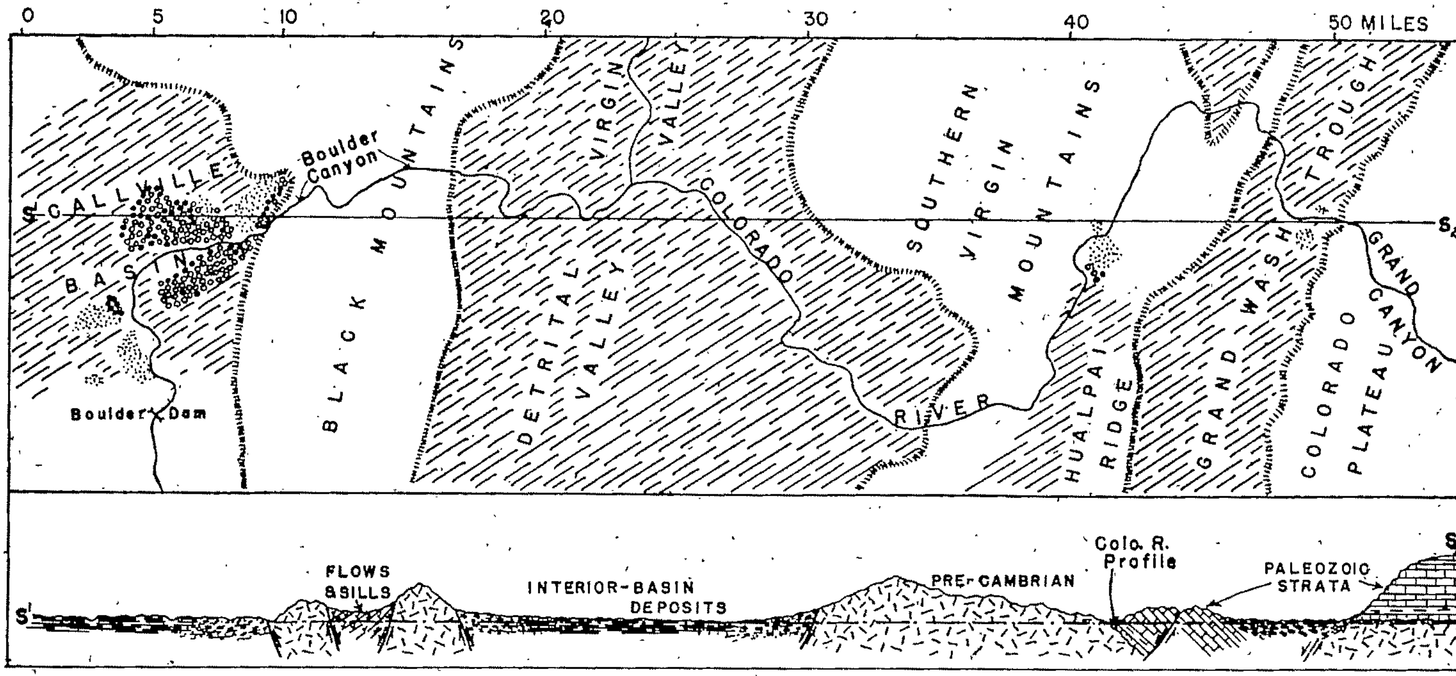


Fig. 2. Course of Colorado River between Grand Canyon and Boulder Dam. Basin deposits between highlands indicated on map by pattern of diagonal lines. Chief outcrops of earliest deposits of Colorado River shown by pattern of small circles. Dotted areas indicate largest remnants of Chemehuevis formation. Below, structure-section along line S^1S_2 (vertical scale about twice horizontal). No river deposits are shown in section.

fold, to cross the much higher plateau blocks into which the Grand Canyon has been cut. Thus, according to Dutton's concept, the course of the Colorado through the canyon is antecedent; the stream, nourished by run-off near its headwaters, was able to cut into the crustal blocks as fast as they were forced upward. Later studies have shown that the great monoclines of this region were formed before deposition of the Eocene sediments, and it is now accepted that the Colorado was superposed on such folds, though the date and the exact mode of superposition are not known. It cannot be said with assurance, however, that Dutton's concept of antecedence in the Grand Canyon is wholly invalid. We do not know how much localized uplift along faults or by differential warping has occurred athwart the stream since its course was established.

Dutton acknowledged that the dates he assigned to the several stages in the history of the river had no basis in direct stratigraphic evidence. The Plateau is subject to active erosion, and hence it contains no record of the stream's history in the form of sedimentary deposits. Dutton's reasoning rested largely on what he knew of the broad regional history, and on his conviction that major consequent stream courses, once they become established, are not subject to radical change.

Evidence West of the Plateau.

INTERIOR-BASIN DEPOSITS.

Blackwelder (1934) has stressed the evidence found west of the Colorado Plateau, where the intermont basins contain quantities of sediments deposited during Tertiary and later epochs. The geology between the Grand Canyon and Boulder Dam, described in some detail in several papers by the present writer (1928, 1936, 1937, 1945), is represented generally in the map and section of Fig. 2. Canyons cut through the southern Virgin Mountains and the Black Mountains reveal pre-Cambrian and Paleozoic rocks, similar to those in the Grand Canyon. The adjoining structural troughs are floored with thick deposits that were laid down under conditions of interior drainage. Coarse fan debris near the mountain borders (Plate 1, A) grades basinward into fine-grained clastic sediments (Plate 1, B), interlayered with evaporites, such as fresh-water limestone, gypsum (and anhydrite), glauberite, and rock salt. As Blackwelder has emphasized, these materials, exposed widely

and clearly along the Colorado, as well as far to the north and south of the river, are nowhere admixed with the characteristic pebbles of a large stream brought from a distance and representing widely dispersed types of lithology. Coarse fragments in the deposits are locally derived from the adjoining highland blocks; bedrock sources are readily identified, and the fragments testify, by their distribution and their predominantly angular shapes, to erosion and deposition through the agency of numerous small ephemeral streams. Isolated as well as confluent fans are easily recognized, with arrangements of coarse debris indicating both torrential stream-flow and mudflows. The finer-grained sediments and precipitates that are spread widely over the basin interiors suggest fluctuations between conditions that foster playas and those responsible for shallow saline lakes. A particularly thick and widespread deposit of nearly pure gypsum and anhydrite in the Virgin-Detrital Trough indicates a large saline lake of long duration (Plate 2). Extensive lavas, as well as fragmental volcanic products, form an important part of the total section. (Longwell, 1936.)

Thickness of the basin deposits is large, but the full measure is not known. In the Muddy and Virgin Mountains, remnants of the coarse marginal facies are found within the mountain borders more than 1,000 feet above the adjoining basin floors. Depths to which the deposits extend beneath these floors are not known, although eroded anticlines and domes reveal only the typical evaporites and fan-debris, many hundreds of feet thick. There is good evidence that faulting at the mountain borders recurred while deposition was in progress, and locally at a later date.

Age-determination of the basin deposits poses a critical problem that so far has defied definite solution. Possibly the deposits represent more than one geologic epoch. Angular unconformities in the section may have more than local significance, and striking changes in lithologic character, even within one basin, suggest important changes in the environment of deposition. Following Stock (1921), I have used the term Muddy Creek formation for a thick series of predominantly yellowish beds in the basin sequence within the intermont areas adjacent to the Muddy Mountains. Proper limits for extension of this formation name, areally and vertically, are not satisfactorily determined. It appears, however, that the typical

Muddy Creek beds comprise the youngest part of the basin sequence recognized thus far, and therefore the actual geologic date of these beds is of critical interest in connection with the Colorado River.

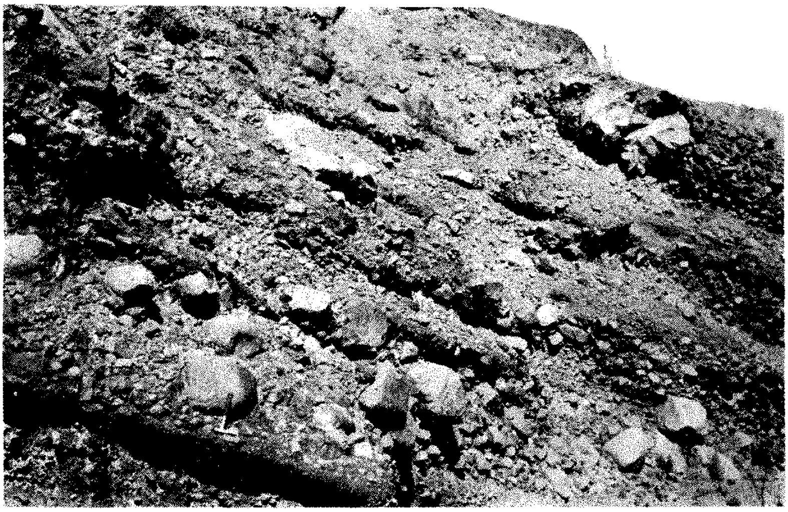
In several publications I have listed the Muddy Creek deposits as of doubtful Pliocene age. Unfortunately other writers have forgotten the query attached to this date, and have quoted my classification of the formation as definitely Pliocene. There is no warrant for this unequivocal dating, and I have been at fault in helping to perpetuate even the dubious classification without more evidence than has been available. The entire basis for the tentative age-assignment was as follows: The Muddy Creek formation resembles the "Panaca beds,"[1] considerably farther north, in which Stock (1921) found bones of characteristic Pliocene mammals; and the Muddy Creek deposits lie with strong angular unconformity on the Horse Spring formation, which initially was correlated with the Upper Miocene Esmeralda and Barstow formations because of peculiar chemical precipitates common to the three units. Later discovery (Rubey and Callaghan, 1936) of Upper Cretaceous fossils in clastic deposits that are essentially conformable with the Horse Spring (though at a much lower stratigraphic horizon), suggests that the latter formation may not be younger than early Tertiary. Moreover, the only fossils thus far reported from the Muddy Creek formation are bones of mammals, which Stock (1921) finds of doubtful value, but suggestive of Miocene date. Therefore, if we are to continue a tentative age-classification of the Muddy Creek formation there is more warrant for Miocene (?) than for Pliocene (?).

Blackwelder (1934) has summarized the evidence for a change in climate in western United States from semi-tropical and humid in the early Tertiary epochs to more temperate and semi-arid or arid after mid-Miocene time. The Muddy Creek deposits record aridity and interior drainage in wide basins that lie athwart the Colorado River. There is no possibility that the river was in its present position west of the Plateau during Muddy Creek time. The suggestion occurs that a stream, either permanent or intermittent, may have developed on the site of the present Grand Canyon, and debouched into the closed basins west of the Plateau. However, if such a stream had any considerable length, it should have contributed

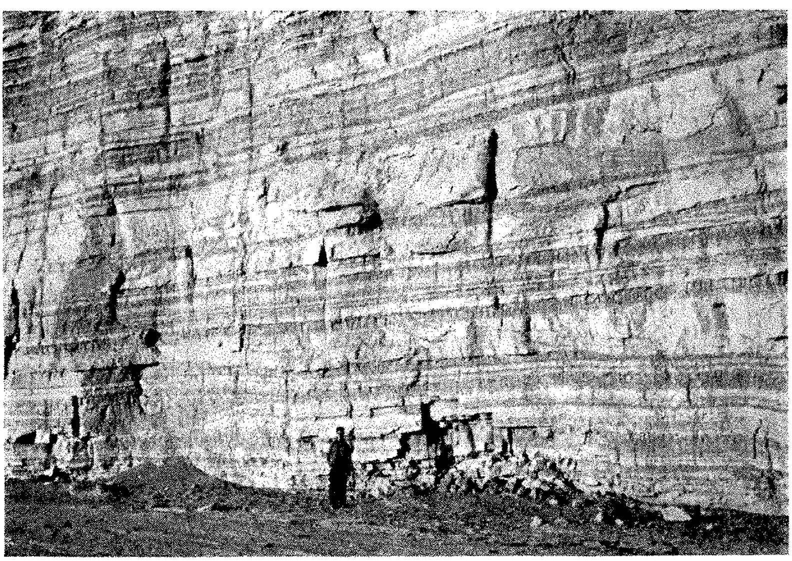
rounded pebbles representing the varie
Grand Wash Cliffs. No such stream-w
found in the basin deposits described abo
seems strongly unfavorable also to any
made by the Colorado River in early T
been faulted down and entirely conceale
that record an arid interregnum. Su
assume that a large valley in the Plate
through the long Muddy Creek interval,
telltale record in basins into which n
poured immense quantities of debris, b
agree with Blackwelder that the sum o
Plateau points strongly to origin of t
position after Muddy Creek time. H
restriction is concerned, the river may
through all of the Pliocene opoch.

The basin deposits in the Grand Was
considerably in character from the typi
in Virgin Valley and Callville Basin, i
Extremely coarse fan-debris, derived ir
pre-Cambrian bedrock of the southern V
was spread eastward into the trough. (
1945). This fan material from the west
individual masses of granite and gneiss up
formed a thick fill, extending almost to t
block (Plate 3, A). In contrast with
ous erosion on the west side of the Tr
on the east side had only moderate devel
fragments are comparatively small, and
short distances west of the Plateau edge (
5 and 19), to intertongue with the much l
built from the west. Thus it is clear t
hanging wall of the Grand Wash fault w
ing or uparching of the Virgin Mountains
ant highland (Longwell, 1937). The b
Plateau must have remained at low altitu
have contributed more generously to fillir

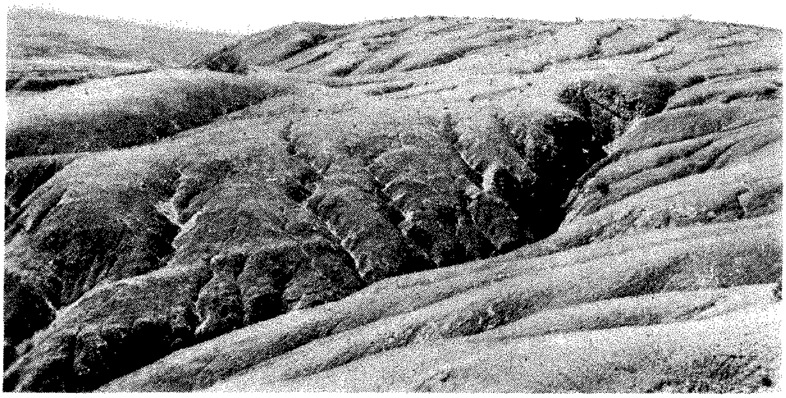
There has been no recurrence of movem
Wash fault since the basin sediments n
down. These deposits, which include lar
stone and freshwater limestone above th



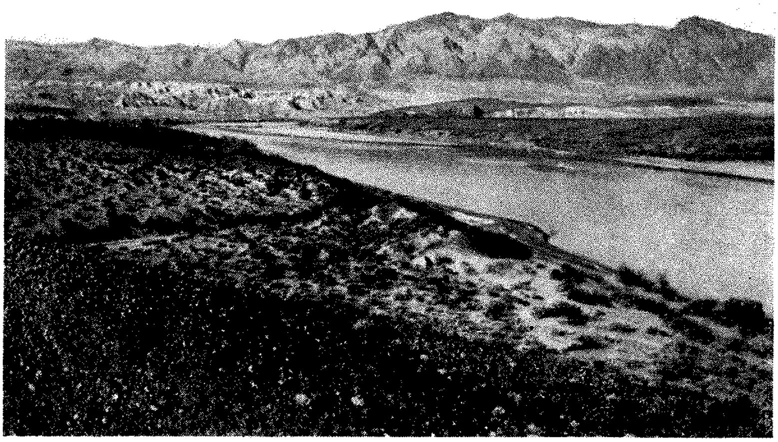
A. Typical coarse fanglomerate of the Muddy Creek formation, within half a mile of the southern Virgin Mountains block. Fragments are of gneiss and granite, which compose the bedrock of this closely adjacent highland. Deposit is firmly cemented. Beds tilted, near fault.



B. Silt and fine sand, with some clay, moderately indurated, and in fairly regular layers. This facies of the Muddy Creek formation is widespread in the Virgin-Detrital and Callville basins, grading laterally into coarse fan debris near the mountain walls. Many parts of the section are rich in gypsum and other salines.

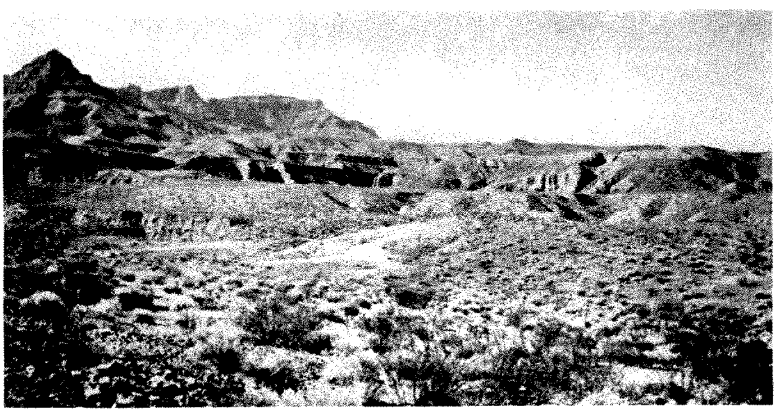


A. Nearly pure gypsum and anhydrite, hundreds of feet thick, flooring an area of several square miles in the Virgin-Detrital trough. Valley of Colorado River, cut into this deposit, is seen in the left background. Note peculiar drainage channels cut into gypsum.



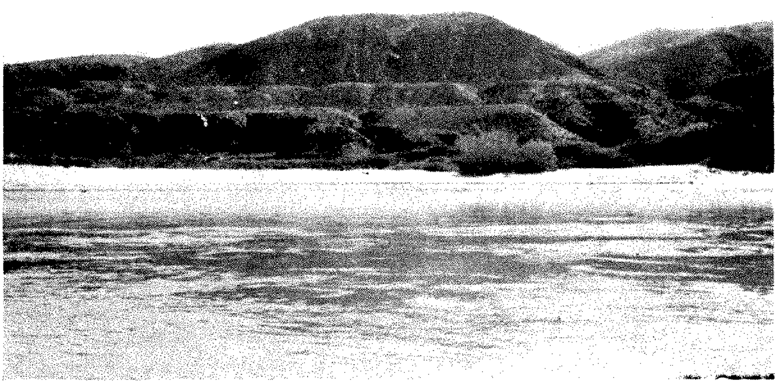
B. Looking west along Colorado River to Black Mountains, about 6 miles distant. Gravel-covered terraces in foreground, underlain by gypsum and other salines. Dark lava in middle distance lies on gypsum and dips southward beneath thick gypsum and anhydrite forming light-colored hills. These salines grade into fanglomerate bordering the mountain block.

A. Looking north at dissected coarse fanglomerate, about 1½ miles west from mouth of Grand Canyon. Grand Wash Cliffs under skyline at right. Large block on pedestal is 15 feet long; it and others at right consist of peculiar porphyritic granite, with closest bedrock source 12 miles west of view, in southern Virgin Mountains.



B. View south, from point near Colorado River, 2 miles west from mouth of Grand Canyon. At left, Paleozoic formations in edge of Plateau. Lower ground on basin deposits—fanglomerate, siltstone, and freshwater limestone, which overlap eroded edges of the Paleozoic strata.

A. Remnant of Colorado River gravels capping terrace 750 feet above modern stream profile. Note overlapping of pebbles that shows direction of current. Hammer gives scale.



B. Gravel-capped terraces north of Colorado River, about 20 miles west of Plateau. The two distinct terraces are about 60 and 100 feet above stream. Remnant of higher terrace in middle background, at 220 feet.

been disturbed by faulting in the five-mile-wide belt between the Plateau and the tilted Paleozoic strata at the eastern margin of the Virgin Mountains (Fig. 2; Plate III, B). Hunt has commented on this fact as follows, (1946, p. 23): "Most of the uplifting [of the Plateau] occurred before late Tertiary time, in the Grand Canyon region, at least, because the late Tertiary Muddy Creek formation overlaps the escarpment formed along the Grand Wash fault, and proves that the major movement on the boundary fault was pre-Muddy Creek." This analysis seems to assume that movement on the great fault must have involved important uplift of the footwall block. Theoretical considerations do not demand such uplift, and the field evidence cited above—comparatively feeble development of fans on the east side of the Trough—indicates continued low altitude of the Plateau block during the faulting episode. Presumably, therefore, the undisturbed deposits in the Trough were later elevated with the plateau block, and have yielded to subsequent erosion because of inferior resistance. Although it has long been accepted doctrine that at its western edge the Plateau was lifted along an abrupt fault boundary, cumulative evidence indicates that regional upwarping included a large section in the Basin-and-Range region, where differential erosion has since reduced to low altitude the areas underlain by basin fill. The upwarping was accompanied by important movements on faults west of the main Grand Wash fault.

In this connection, it should be emphasized that correlation of the deposits in the Grand Wash Trough with the Muddy Creek formation of the Virgin Valley and Callville Basin is open to very serious question (Longwell, 1936). The Grand Wash section has, at the base, a fan deposit of exceptional coarseness; the section is deficient in saline deposits, as compared with the Muddy Creek formation; and it has as its upper member a large thickness of freshwater limestone not matched in the Muddy Creek deposits, but strikingly similar to some limestone in the older Horse Spring formation (Longwell, 1928).

At the suggestion of K. E. Lohmann, of the U. S. Geological Survey, I collected from the Hualpai limestone, in the Grand Wash Trough, a large suite of specimens, in the hope that diatoms generally present in such lake deposits of Middle and Upper Tertiary age might provide a key for dating. Since no

diatoms were found in the collection, there is the suspicion, based on negative evidence, that the limestone may be pre-Miocene in age. Thus it is possible that basin deposits were formed athwart the course of the present Colorado River in more than one Tertiary epoch.

COLORADO RIVER DEPOSITS.

Deposits made by the through-flowing Colorado are unmistakable. They contain, as a characteristic ingredient, gravel made up of rounded pebbles and cobbles, representing a large

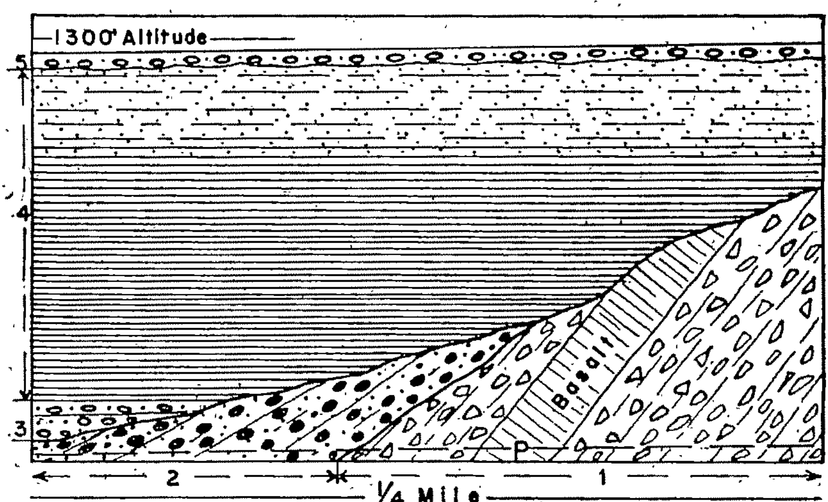


Fig. 8. Generalized section in Callville Basin showing relations between (1) Muddy Creek formation, (2) oldest Colorado River deposits (cemented), (3) next younger river gravels, (4) Chemehuevis lake beds, (5) high terrace capped with river gravels. Different patterns for the Chemehuevis represent predominant clay and silt in lower part, predominant sand in upper part. *P*, profile of Colorado River, altitude about 675 feet.

number of bedrock types found in the Plateau. Commonly these gravels have also an imbricate arrangement that reflects the direction of current-flow (Plate 4, A). These coarse ingredients are interbedded with varying proportions of sand and silt (Plate 5, A).

The characteristic river deposits found between the Plateau and Boulder Dam fall into three general divisions, representing more or less definite episodes in the history of the stream.

These divisions, in order of increasing age, are: (1) modern deposits along the channel of the stream as it was operating before the rise of Lake Mead; (2) similar deposits capping a series of large terraces distributed through a vertical range of several hundred feet above the modern stream profile (Plate 4, B); (3) somewhat indurated beds, locally much deformed, into which the modern stream has cut (Plate 5). Relations of gravels in the three general divisions, as seen in Callville Basin, are represented in Fig. 3. Interposed between divisions (2) and (3) (between 5 and 2 of Fig. 3) is a thick deposit of sand, silt, and clay,—the Chemehuevis formation (Longwell, 1936). In brief outline, the history recorded in this series of deposits is as follows. After the river had cut its valley to essentially its present form and depth, with adjustments to local faulting and folding across its course, a change of conditions caused deposition of a thick fill, which reached to a height of several hundred feet, and probably as much as 1,000 feet, above the valley floor. In large part these deposits appear to be definitely lacustrine, and therefore the river must have been ponded, possibly by broad upwarping in the lower part of its course. Since the filling occurred during the Pleistocene, perhaps part of it reflects climatic change that resulted in overloading. After the filling reached a maximum, the river again cut down, removing the major part of the fill and developing a fine set of gravel-capped terraces. Although the Chemehuevis sediments are unconsolidated and easily eroded, hundreds of remnants lie at various levels along the valley below the Grand Canyon, the larger ones in locations sheltered from lateral cutting by the stream (Plate 6).

Definite dating of the oldest river deposits in the section would set a minimum age of the Colorado in its present course. These old beds were exposed at several points along the valley before Lake Mead was filled, but the best and most extensive exposures were in Callville Basin, where the beds were turned up sharply and folded in a wide belt adjacent to a fault at the border of the Black Mountains (Plate 5). All of the deposits in this deformed section, several hundred feet thick, were cemented well enough to stand in cliffs. The deformation was entirely pre-Chemehuevis. I found in the upturned beds of gravel and silt the femur of a camel, which was identified as "not far from *Camelops huerfanensis*," and was pronounced Pleistocene

in age (1936, p. 1442). However, the bone was recently submitted to George Gaylord Simpson, who doubts that it belongs to the genus *Camelops*, and states that "the specimen could very well be Pliocene or Pleistocene."[1] Thus we have the possibility that as early as sometime in the Pliocene epoch the Colorado, in the stretch west of the Plateau, had fashioned its valley to essentially its present form.

None of the fragmentary remains of plants and animals that have been found in the Chemehuevis formation near the Colorado River appear to have diagnostic value. However, light-colored clays and silts that are either part of or closely related to the formation, extend up tributary valleys, and these deposits have yielded abundant fossils, both vertebrate and invertebrate. In Las Vegas Valley I have collected elephant teeth, fragmentary bones of camels and horses, and small snail shells representing a number of genera and species. Some years ago I submitted specimens of the snails to the late Frank C. Baker, who made the following identifications:

Valvata humeralis californica Pils
Physa virginea Gould
Gyraulus similaris F. C. Baker
Gyraulus vermicularis hendersoni Walker
Stagnicola bulimoides techella Hald
Pisidium. Several species.
Fossaria species indet, possibly new.
Pupilla muscorum Linn
Succines oregonensis gabbi Tryon?

The following comments accompany the list:

"The deposit may be safely referred to the Pleistocene . . . Some of the species listed live in swampy places or in ephemeral pools. Others are known to live in larger lakes, more or less permanent . . . The two groups of species frequently live in the same place, the mud-loving species along the shore or in sheltered places, and the others in the more open part of a lake" (1932).

Simpson (1933) studied and identified a number of vertebrate fossils collected from the light-colored beds near Las Vegas. Included in his list are horses, camels, an elephant (Columbian

[1] Letter, dated 7 May, 1946.

mammoth), and a bison. Of the entire group he says, "This fauna is obviously of Pleistocene character. Of the forms of mammals so far known, at least 65 per cent are extinct, and these all belong to species or genera apparently confined to the Pleistocene." Simpson disagrees, however, with the conviction of some paleontologists that this association of extinct mammals is a criterion of Early Pleistocene date; he refers to evidence indicating that many of the forms survived until the Late Pleistocene.

Rose (1938) has studied the light-colored clays and silts in the Las Vegas and neighboring valleys. He agrees with me that these deposits seem to be closely related to the Chemehuevis formation.[2]

POSSIBLE INTERPRETATION OF THE EVIDENCE.

As explained on an earlier page, I agree with Blackwelder that the evidence now in hand points strongly to the origin of the Colorado in its present course after the Muddy Creek formation was deposited. However, the tentative dating of this formation as Pliocene has always been questionable, and now seems to lack any basis of tangible evidence. If we accept the probable Miocene date for the Muddy Creek suggested by Stock, all of the time since the late Miocene may be invoked for development of the river and its valley. The supposed basis for definite Pleistocene age of the oldest recognizable Colorado River deposits now appears to be invalid, and these deposits, which indicate an advanced stage in development of the river valley as we know it, may date well back in the Pliocene epoch. The advanced degree of cementation and the strong local deformation of these beds contrast with the lack of consolidation and of disturbance in the overlying Chemehuevis formation, and suggest a considerably earlier date of origin. It is well to consider also the direct implication of the Chemehuevis formation, in connection with the history of the Colorado. This deposit was formed after the river had cut its valley to its present form and depth. Large remnants of the Chemehuevis fill were found on the valley sides directly below the mouth of the Grand Canyon (Plate 6, B), showing unmistakably that cutting of the canyon was essentially complete

[2] Personal communication.

before the fill was introduced, perhaps fairly early in the Pleistocene epoch. Thus the suggestion that the river began its history about the beginning of Pleistocene time seems wholly untenable.

On the other hand, arguments that the Colorado River has occupied essentially its present course since early Tertiary time, as urged by Dutton and recently by Hunt, do not carry conviction. Lacking direct evidence for its support, the concept seems to rest on reasoning somewhat as follows: The Plateau region has been above the sea since late Cretaceous time. There is evidence that a fairly moist climate prevailed in western United States during the early Tertiary epochs, and therefore an integrated system of drainage channels must have become established on the area of the present Plateau. These channels would have been incised during later uplift. In Dutton's view a drainage system, once it is developed, is essentially "immutable." Moreover, in his interpretation the course of the Colorado persisted even in spite of strong upfolding across its path, a conclusion that has not survived later study.

Hunt makes the following statement in favor of his concept: "The course of the Colorado at Grand Canyon lies across one of the highest parts of the plateau, high structurally and topographically, so this part of the River's course undoubtedly dates from a time when the adjoining part of the Plateau was much lower with respect to the drainage basin upstream" (1946, p. 24). True enough; but at what date did uplift occur to produce the present high altitude of the Grand Canyon district? Hunt interprets the evidence at the Grand Wash fault as pointing to the main uplift "before late Tertiary time." The weakness of this analysis is explained above (p. 824). Moreover, cumulative regional evidence seems to establish a post-Miocene date for the great epeirogenic movement responsible for high altitudes in the Rocky Mountains and adjoining plateaus (Fenneman, 1931, p. 107).

Hunt recognizes that deposits of local derivation lie across the course of the Colorado west of the Plateau, and that the river could not have been in operation there while this deposition was in progress. He suggests that elevation of the High Plateaus may have created "a rain shadow to the eastward along 300 miles of the river's course," and that the resulting aridity, together with differential uplift across the valley in the Grand

Canyon district, may have caused temporary ponding within the Plateau area, thus permitting basin deposits to accumulate farther west. However, I know of no evidence indicating that the High Plateaus were elevated earlier than the Rocky Mountains, from which the Colorado derives most of its flow at present. Moreover, Hunt's suggestion appears to underestimate the significance of the basin deposits that border the river for hundreds of miles west of the Plateau. These cannot be described as local "conglomerates" and "gravel"; they are vast sheets of waste that filled wide structural basins between mountain ranges. This waste extends far below the river channel, as shown by eroded folds and domes; it once overtopped important parts of the Virgin, Muddy and Black Mountains, as indicated by remnants high above the present basin floor. The thickness, areal extent, and character of this basin fill bear eloquent testimony to a long régime of interior drainage, under an arid climate, throughout the basins now crossed by the through-flowing Colorado River.

Presumably the river was superposed from the upper surface of the basin fill, and in this way the deep canyons, such as Boulder Canyon, were cut through the ranges that now extend across the course of the river. Superposition of the river across these ranges must have occurred while the Grand Canyon was being cut into the Plateau block. The narrow gorge does not continue west of the Grand Wash Cliffs, merely because the weak fill in the intermont basins has yielded rapidly to erosion. An old concept that downfaulting is solely responsible for the low altitudes of the intermont basins is in need of revision. There is clear evidence, extending into the Great Basin far beyond the Colorado River drainage, that vast quantities of intermont waste were swept out by a system of integrated stream channels during the reign of more pluvial climates in Pleistocene time. Along the Colorado itself, excavation of the weak intermont deposit probably has been continuous since the through-flowing stream established its course, except during the interval of aggradation that resulted in the Chemehuevis formation.

Those who argue for earlier origin of the Colorado will continue to raise the question of drainage disposal in the Plateau area during Miocene and pre-Miocene time. Geomorphic features, such as incised-meander patterns and remnants of erosion

surfaces with subdued relief, furnish
advanced development of the present s
of the "canyon cycle" (Moore, 1926; (
ever, we are without any assured dat
geomorphic features. There has beer
Miocene for vast changes in landsc
uplift has given free play to the agent
to project the present drainage syster
Tertiary encounter possible difficulty i
of the regional history. Intensive oro
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affected a wide belt directly west of th
of the Cretaceous period. Presumably
zone extended across the course of the p
early Cenozoic time, with structural g
raphy opposed to any westward dr
Plateau area. Logically the early d
may have been southward, since ranges
lay to the east, and the Uinta arch to
system of streams may have removed f
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developed chiefly in the Mesozoic forma
pal valleys reached the old-age stage b
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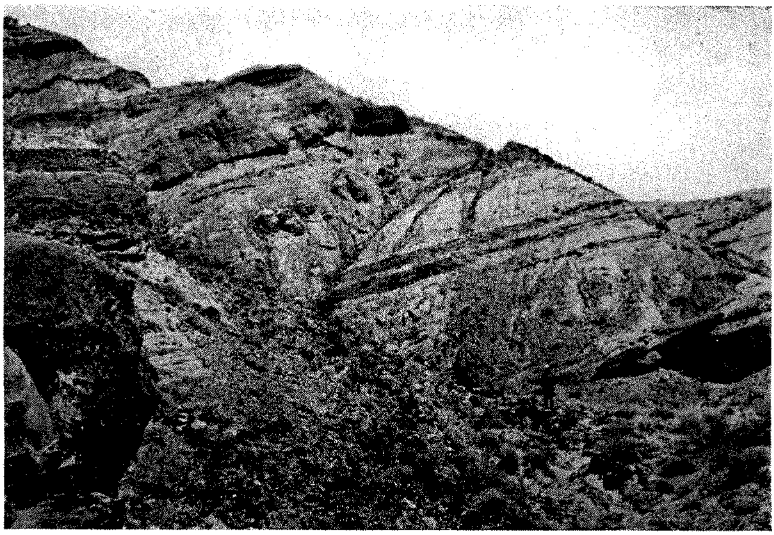
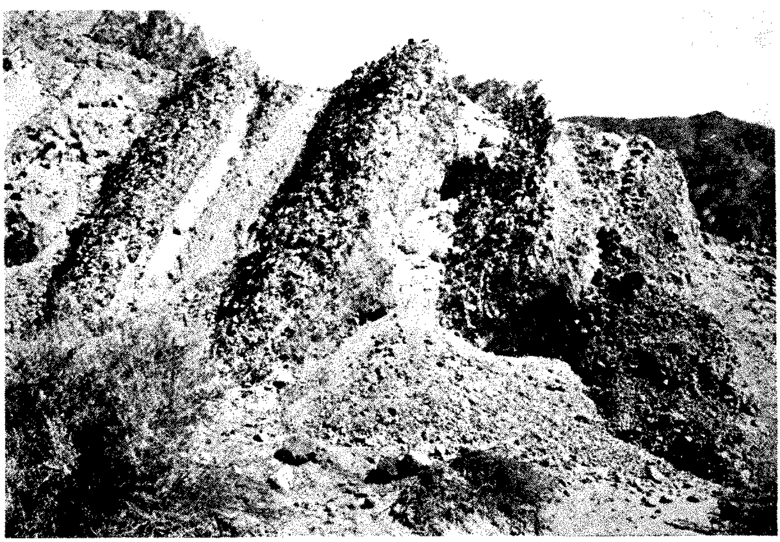
that may have been abandoned or rever
of drainage.

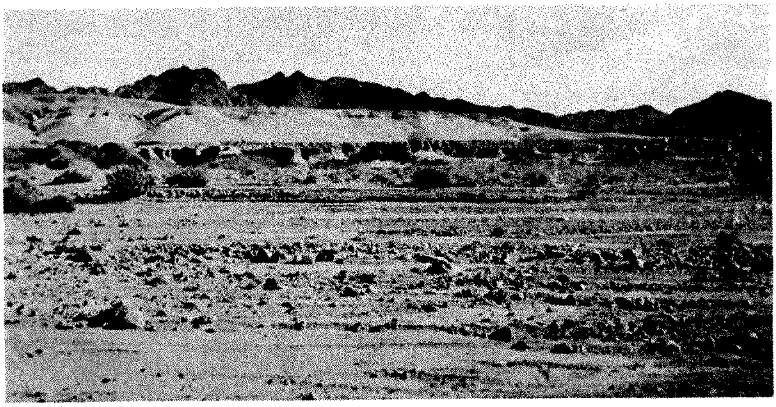
The Miocene seems to have been an
activity in the Cordilleran region. Vas
volcanic ejecta lie in western New Mexi
possibly across one or more outlets of
tem that served the Plateau area. Upl
ing large-scale warping and faulting,
the close of the Miocene, and continued
Pliocene. It is recognized that such m
plateaus caused radical changes in dr
reversal of flow in some large valleys. I
the chief results of volcanic obstructio
movement, may have been reversal of d
part of the area and initiation of a new
of the streams—the San Juan, the Gree



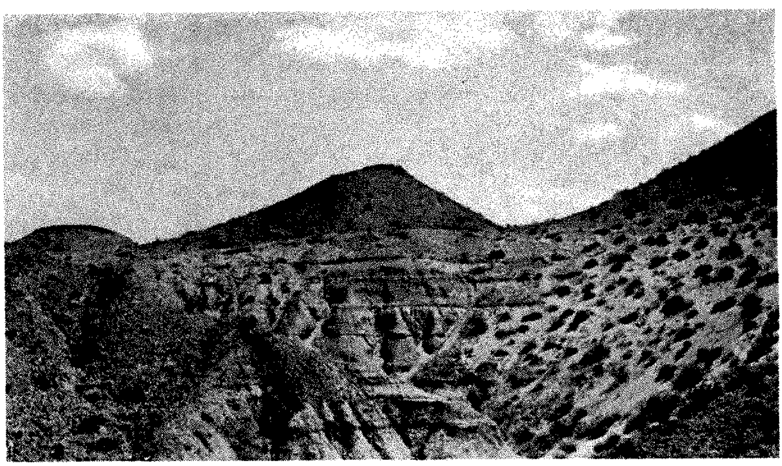
A. Old Colorado River deposits in Callville Basin, 100 to 200 feet above modern stream. Dark beds made of gravel (like that in Pl. 4, *A*); light-colored beds of silt and fine sand. All beds fairly well indurated, and tilted strongly westward.



B. Indurated Colorado River deposits near mouth of Boulder Canyon, tilted steeply near a large fault. Scale given by hammer, left of center. Advanced cementation of gravels indicated by form of beds at protruding edges.



A. Large remnant of Chemehuevis deposit north of the river near mouth of Boulder Canyon. Thickness of 600 feet in exposed edge of remnant. Lower, cliffy part chiefly clay, in thin layers; upper part chiefly sand, in thick, cross-bedded layers like those shown in *B*, below.



B. Characteristic remnant of Chemehuevis formation on valley side, ½ mile west of Plateau, about 150 feet above river. Deposit made up of gigantic "varves," each consisting of a thick sand layer, ending upward in a thinner layer of clay. Nine of these units in view, ranging in thickness from 7 to 10 feet each. River gravel, about 50 feet thick, at top.

as well as the upper part of the Colorado itself—possibly kept essentially their old locations. Breaking down by faulting of the old mountain barrier west of the Plateau may have played an important rôle in determining the choice of the new outlet. If the uplifted Plateau surface was essentially a peneplane, super-position of the new drainage channel across the bevelled East Kaibab monocline and other structural features must have started from this surface, along a consequent course determined by topographic irregularities. Some ponding would have been inevitable in the early stages of establishing a new outlet; however, all traces of the resulting temporary shallow lakes must have been destroyed by later erosion, which has also removed vast quantities of rock from the weak Mesozoic formations, particularly in the area east of the Grand Canyon district.

In outlining the foregoing hypothesis, it has been assumed that the Plateau has had exterior drainage continuously through the Cenozoic era. However, as Blackwelder suggests, the region probably was unable to support a through-flowing stream like the Colorado for a considerable period after the onset of aridity in the western interior, about the middle of the Miocene epoch, and until regional uplift created mountain heights capable of condensing adequate moisture to nourish large streams. During such an interval the drainage of the Plateau area would have been accomplished by intermittent streams ending in a number of separate closed depressions, as in the Great Basin region at present. Miocene volcanic materials may have accumulated during this time in critical low areas in the southern part of the present Plateau; and in early stages of regional uplift, differential warping may have aided in producing a slope generally to the north in those areas. When the Cordilleran region attained such altitude that increased precipitation in the Rocky Mountains supplied a surplus of runoff into the Plateau, the configuration of the surface may have been such as to guide the overflow along a new consequent course to the west. This version of the hypothesis resembles Blackwelder's, modified to account for drainage during early Tertiary time.

The suggestion of an earlier drainage southward from the Plateau does not rest on any direct field evidence known to me.

However, in the field of speculation there are logical possibilities other than persistence of a drainage pattern from Eocene time to the present. Evidence found west of the Plateau strongly suggests an alternative possibility.

CONCLUSION.

The title of the present discourse is properly in the form of a question, since it is not now possible to outline a full history of the Colorado River drainage without resort to speculation. However, evaluation of the evidence now in hand definitely favors a date of origin considerably more remote than that suggested by Blackwelder, and much later than that proposed by Dutton and Hunt. Although the exact age of the critical Muddy Creek deposits is not yet fixed, the available fossils do not suggest a date earlier than Miocene, and the evidence of regional aridity favors an Upper Miocene assignment rather than older. Since fossil evidence in the oldest recognizable gravels and silts laid down by the Colorado River indicates a date of deposition not earlier than Pliocene, presumably the river acquired its present course west of the Plateau after late Miocene time.

Students of the Grand Canyon are awed by its immensity, and some may question whether all of the time since the end of the Miocene is adequate for this gigantic task of excavation. Several estimates agree on 10,000,000 years as the right order of magnitude for the time elapsed since the start of the Pliocene epoch. Would the cutting of the canyon require a longer interval? Surely our knowledge of rates of erosion is not a reliable guide in computing length of time. A dependable history of the Colorado River will be possible only when all of the critical features of the valley can be dated by accepted geologic methods.

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STUDIES IN THE MICA GROUP; THE BIOTITE-PHLOGOPITE SERIES.*

E. WM. HEINRICH.

ABSTRACT. The chemistry of the biotite-phlogopite series is discussed and examples are given of members with maximum percentages of the constituent elements in order to illustrate the variation in chemical composition. Several hundred analyzed biotites and phlogopites are grouped into eight classes according to geologic occurrence and their $Fe_2O_3+TiO_2-FeO+MnO-MgO$ ratios are plotted by groups on triangular diagrams. That each group occupies a restricted field in the diagrams illustrates the fixed relationships between chemical composition and geologic occurrence. However, biotites from extrusive rocks do not fit the diagrams. The relation beween the indices of refraction and chemical composition is shown by plotting γ against Wt. % $FeO+2(Fe_2O_3+TiO_2)$. Ferric iron and titanium appear to have an effect on the indices in the order of twice that of ferrous iron.

INTRODUCTION.

IN the spring of 1942 the writer began an investigation of the mica minerals in an attempt to correlate variations in chemical composition with geological occurrence, and to a lesser extent physical properties with chemical composition. An extensive survey of the literature was made to obtain a collection of analyses and related data that would be as complete as possible. During the fall of 1945 the analyses were studied and an attempt was made to present the results in a systematic manner. The writer is greatly indebted to the late Professor Harry Berman who suggested the study and contributed much to its early progress, to Professor E. S. Larsen for valuable discussions during its later progress, and to Professor C. S. Hurlbut for a critical reading of the manuscript.

Nearly 300 analyses of biotites and phlogopites were obtained from the literature, and eight unpublished analyses were made available to the writer by Professor E. S. Larsen. In some analyses the source of the material was not stated, and consequently the data were valueless for the first part of this study. In many cases optical and physical properties were not given for the analyzed micas, and these analyses could not

* Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 280.

be used for the second part of the study. Biotites that contain excessive water and correspondingly low potash were disregarded as being weathered. Analyses of the rarer members of the series, such as manganophyllites, manganphlogopite, barium biotites, and calciobiotite, were not used in plotting the triangular diagrams. The publication of the large number of tabulated analyses is not attempted, but the analyses and their sources are retained in the writer's files and are available for reference.

MEMBERS OF THE BIOTITE-PHLOGOPITE SERIES.

The general formula in the biotite-phlogopite series can be expressed by: $W_4(X,Y)_{8-12}Z_{16}O_{40}(O,OH,F)_8$ (Berman, 1937), where

W = K, minor Na,Ba,Ca
X = Mg, Fe″, Mn″
Y = Al, Fe‴,Ti^{IV}, Mn‴, and rarely Ti‴
Z = Si, Al in a ratio of 5:3 to 6:2

In Table I are presented a number of analyses which were chosen to indicate in a general way the maximum content of various constituents or pairs of constituents in members of the series.

Micas rich in either ferric iron or ferrous iron are common, but relatively few biotites contain both iron atoms in more than moderate amounts. Most biotites contain small amounts of Ti^{IV}, with a recorded maximum of about 12% TiO_2. Biotites that contain high percentages of TiO_2 are generally low in Fe_2O_3 but may be rich in either FeO or MgO. Analysis 5 is an example of a biotite with a moderate amount of ferrous iron and a high TiO_2 content. Analysis 6 is a phlogopitic biotite that has a high content of titanium associated with large amounts of MgO. Trivalent titanium has been reported to occur in biotite (Amal. 7), but it appears to be uncommon.

Except in the manganophyllites, manganese, either divalent or trivalent, is uncommon. In biotites small amounts of MnO are associated with a high content of either ferric or ferrous iron (Analyses 8 and 9). The highest content of divalent manganese is reported from a manganphlogopite (Analysis 10). Some manganophyllites contain both divalent and trivalent

manganese; others have only divalent manganese; and in a few the manganese is chiefly in the divalent form.

The alkali metals are the minor variables in the series. Sodium substitutes for potassium in limited amounts in only a few biotites. Calcium and barium are present in very limited quantities. A maximum of about three atoms of sodium may occur either in iron-rich biotites or in phlogopites (Analyses 13 and 14). Barium appears to accompany only magnesium-rich biotites or phlogopites (Analyses 15 and 16). The highest content of calcium is reported from a micaceous mineral from an altered limestone block in a tuff at Vesuvius (Analysis 17).

CHEMICAL VARIATION WITH GEOLOGIC OCCURRENCE.

In determining the genetic grouping of the mica it is necessary to note whether it has formed as a normal constituent of the rock or whether it crystallized under atypical conditions. For example, biotite from a fayalitic nodule in a granite has formed under conditions different from those under which the ordinary granitic biotite developed and would be expected to show a consequent difference in chemical composition. Likewise biotite from a schist inclusion in pegmatite formed in an environment different from that of ordinary pegmatitic biotite. In each case the histories of the two types are different, and the micas cannot be placed in the same genetic group.

The biotite-phlogopite micas occur as primary constituents of many types of igneous rocks, both intrusive and extrusive, which range in composition from felsic to ultramafic. They also occur in pegmatites, metamorphosed limestones, and hydrothermal veins. Biotite is a common constituent of gneisses, schists and other metamorphic rocks. Undoubtedly the mineral forms under a wide variety of conditions. The chemical composition is a reflection not only of the elements and proportions thereof available for formation but also of the geologic environment under which the mineral crystallizes. Thus biotites from syenites differ from those in granites, and those, in turn, differ from biotites from more mafic rocks. Biotites from extrusive rocks are different in composition from those in the intrusive equivalents even though the rocks may be very similar in chemical composition. Schauberger (1927), in his study of biotites of the alkalic rocks of Bohemia concluded that the iron-rich biotites occur in the felsic rocks of the petrographic prov-

ince and the magnesium-rich ones in the mafic rocks and that the composition of the biotites, with respect to iron and magnesium, was related to the Fe-Mg ratio in the parent rock and not to the absolute amounts of Mg and Fe present.

To express this variation in a quantitative way it was necessary to decide upon the fundamental chemical variants and then to group the occurrences systematically. After some experimentation a triangular diagram with the plots, $Fe_2O_3+TiO_2$, $FeO+MnO$, and MgO was chosen. The occurrences were grouped as follows:

1. Granitic pegmatites
2. Granites, quartz monzonites, granodiorites
3. Tonalites, diorites
4. Gabbros
5. Peridotites and other ultramafics
6. Syenites, nepheline syenites, and syenitic pegmatites
7. Gneisses and schists
8. Metamorphosed limestones

Very few analyses have been made of biotites from hydrothermal veins, and the general characteristics of this group could not be determined. Likewise relatively few biotites from extrusive rocks have been analysed.

BIOTITES FROM GRANITIC PEGMATITES.

It is recognized that granitic pegmatites may contain hydrothermal biotite, and every effort was made to include in this group only primary magmatic biotites. These biotites (Fig. 1) are characterized chiefly by a very high content of FeO, which has a maximum of about 30%. Both MgO and $Fe_2O_3+TiO_2$ are less than 10%, with MgO generally the smaller.

BIOTITES FROM GRANITES, QUARTZ MONZONITES, GRANODIORITES.

Many analyses have been made of biotites from granites and granodiorites. The FeO content ranges from about 12% to 25% (Fig. 2). The content of $Fe_2O_3+TiO_2$ generally is less than 10% and the MgO content may be as high as 12%. The few analyzed biotites from rhyolites and latites fall at a considerable distance outside of the general field.

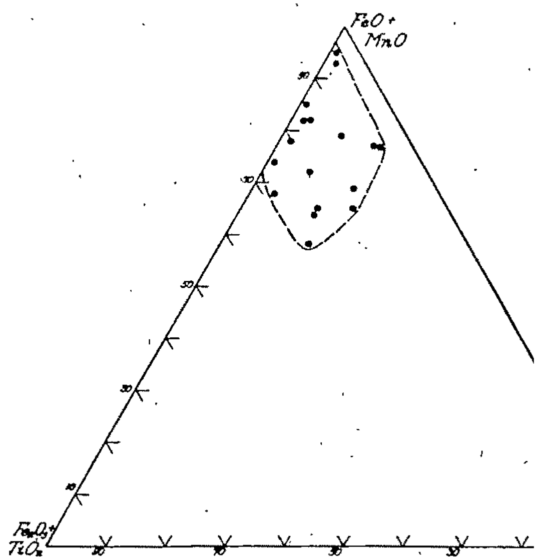

Fig. 1. Biotites from Granitic Pegmati

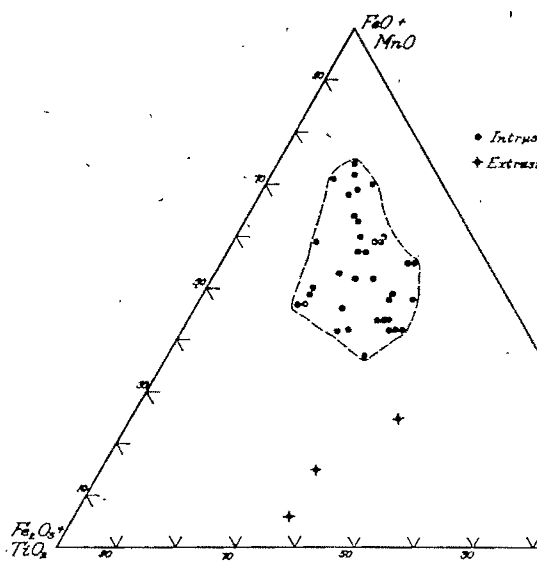

Fig. 2. Biotites from Granites, Quartz Monzonites

BIOTITES FROM TONALITES AND DIOR

Figure 3 shows the distribution in compos
from tonalites and diorites. The field lies withi
granitic field (Fig. 2), but is restricted to the

No.	Name	Constituent	Formula
1.	lepidomelane	Fe″	$K_{4.0}\ Na_{0.5}\ Fe''_{9.5}\ Mn_{0.08}\ Fe'''_{2.3}\ Ti_{0.08}\ Mg_{0.04}$
2.	lepidomelane	Fe‴	$K_{3.8}\ Na_{1.3}\ Ca_{0.3}\ Fe''_{2.0}\ Mn_{0.7}\ Fe'''_{6.1}\ Ti_{1.2}\ Mg$
3.	lepidomelane	Fe″ and Fe‴	$K_{3.2}\ Na_{1.0}\ Fe''_{3.7}\ Mn_{0.4}\ Fe'''_{4.6}\ Mg_{0.04}\ Al_{6.8}\ Si$
4.	phlogopite	Mg	$K_{3.2}\ Na_{0.2}\ Fe''_{0.07}\ Mg_{13.0}\ Al_{3.9}\ Si_{18.4}\ O_{46.9}\ (O$
5.	wodanite	Ti⁗ and Fe″	$K_{3.2}\ Na_{1.0}\ Ca_{0.3}\ Fe''_{2.7}\ Mn_{0.02}\ Fe'''_{0.7}\ Ti_{2.9}\ Mg$
6.	phlogopitic biotite	Ti⁗ and Mg	$K_{4.0}\ Na_{0.1}\ Ca_{0.2}\ Ba_{0.1}\ Fe''_{0.9}\ Fe'''_{0.7}\ Ti_{2.0}\ Mg_{8}$
7.	biotite	Ti‴	$K_{3.8}\ Na_{0.9}\ Fe''_{7.8}\ Mn_{0.2}\ Ti''''_{0.4}\ Ti'''_{0.5}\ Mg_{3.3}\ A$
8.	biotite	Mn″ and Fe″	$K_{3.8}\ Na_{0.6}\ Ca_{0.6}\ Fe''_{5.8}\ Mn_{1.0}\ Fe'''_{2.7}\ Ti_{0.4}\ Mg$
9.	lepidomelane	Mn″ and Fe‴	$K_{3.2}\ Na_{1.6}\ Fe''_{2.3}\ Mn_{1.4}\ Fe'''_{6.0}\ Mg_{1.5}\ Al_{4.5}\ Si$
10.	manganphlogopite	Mn″ and Mg	$K_{1.8}\ Na_{0.6}\ Ca_{0.8}\ Fe''_{0.6}\ Mn_{4.7}\ Ti_{0.1}\ Mg_{8.0}\ Al_{5.4}$
11.	manganophyllite	Mn″ and Mn‴	$K_{3.5}\ Na_{0.4}\ Mn''_{2.3}\ Mn'''_{0.7}\ Fe'''_{1.0}\ Mg_{0.4}\ Al_{8.0}\ S$
12.	manganophyllite	Mn‴	$K_{3.1}\ Na_{0.8}\ Fe'''_{0.9}\ Mn'''_{1.8}\ Mg_{9.8}\ Al_{4.7}\ Si_{10.7}\ O_{4}$
13.	phlogopite	Na	$K_{2.3}\ Na_{2.9}\ Ca_{0.03}\ Fe''_{0.2}\ Fe'''_{0.5}\ Ti_{0.07}\ Mg_{9.4}\ A$
14.	siderophyllite	Na	$K_{2.3}\ Na_{3.0}\ Ca_{0.4}\ Fe''_{4.8}\ Mn_{0.2}\ Fe'''_{3.4}\ Ti_{0.3}\ Mg_{1}$
15.	barytbiotite	Ba and Ca	$K_{1.9}\ Na_{0.2}\ Ca_{2.6}\ Ba_{0.6}\ Fe''_{0.1}\ Fe'''_{0.5}\ Mg_{11.1}\ A$
16.	phlogopite	Ba	$K_{2.9}\ Na_{0.6}\ Ba_{0.3}\ Fe''_{0.2}\ Fe'''_{0.5}\ Mg_{11.9}\ Al_{4.7}\ Si$
17.	calciobiotite	Ca	$K_{3.0}\ Na_{2.2}\ Ca_{4.3}\ Mn_{0.07}\ Fe'''_{0.4}\ Ti_{0.02}\ Mg_{4.2}\ A$
			* May be somewhat weathere

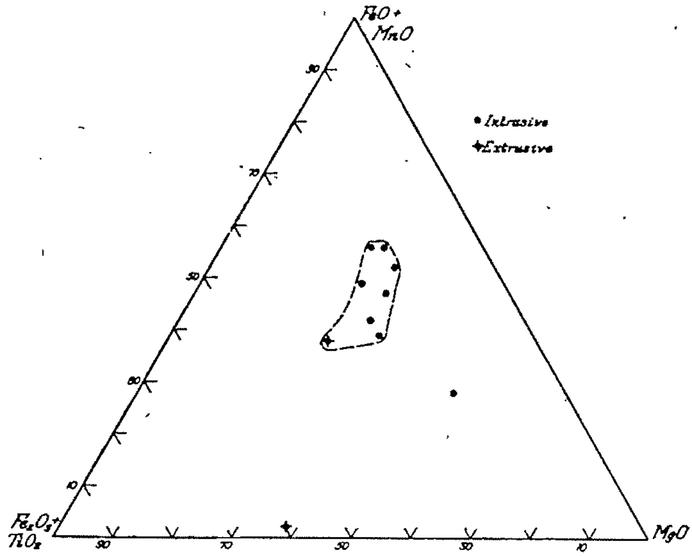

Fig. 3. Biotites from Tonalites and Diorites.

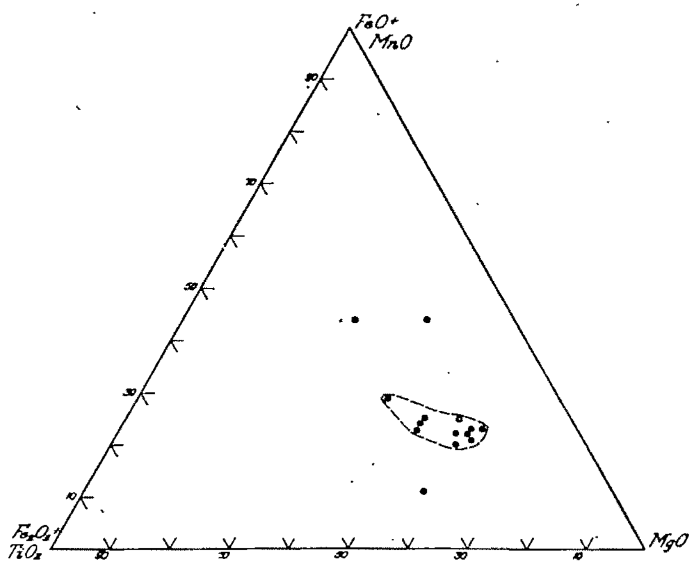

Fig. 4. Biotites from Gabbros.

MgO. In general the FeO content is lower, but the range of $Fe_2O_3+TiO_2$ is the same. One of two biotites from andesites falls within the field, but the other is at a considerable distance from it.

BIOTITES FROM GABBROS.

Most biotites from gabbros and other mafic intrusive rocks have an MgO content of 15-20% (Fig. 4). The ratio of FeO+MnO to $Fe_2O_3+TiO_2$ of many approximates 1:1. The maximum FeO content is about 10%, and the maximum Fe_2O_3 content is about 8%; but TiO_2 is high in those in which the ferric iron is low. Some of the basaltic biotites fall within the

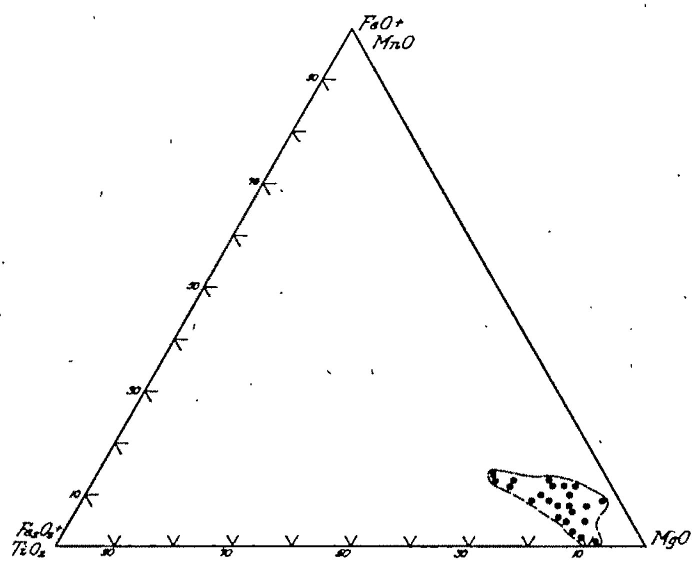

Fig. 5. Biotites and Phlogopites from Periodotites and other Ultramafics.

field of concentration, and others lie outside of it. The extrusive biotites of this group are more similar in chemical composition to their intrusive equivalents than in any other group.

BIOTITES FROM ULTRAMAFIC ROCKS.

Micas of the ultramafic rocks are phlogopites or phlogopitic biotites that contain a maximum of about 6% Fe_2O_3 and 5% FeO. The content of TiO_2 is generally very low. The MgO maximum is nearly 30%. Many of these micas appear to be intermediate in composition between true phlogopites of the metamorphosed limestones and biotites from less mafic intrusive rocks.

BIOTITES FROM SYENITES, NEPHELINE SYENITES, AND SYENITIC PEGMATITES.

Biotites from syenitic rocks contain the highest percentages of Fe_2O_3. Included in this group are the lepidomelanes, a term that has been applied to biotites rich in either ferric or ferrous iron or both. The FeO content may also be very high, with a maximum of nearly 32%, but in general it is less than in bio-

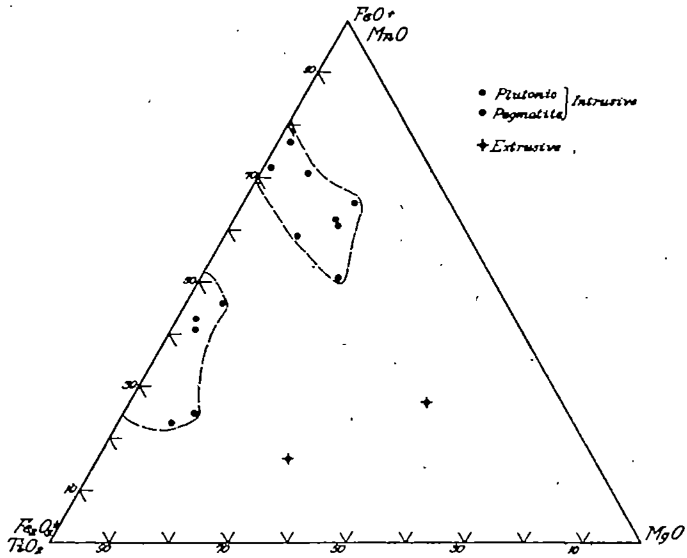

Fig. 6. Biotites from Syenites, Nepheline Syenites, and Syenitic Pegmatites.

tites from granitic pegmatites (Fig. 6). The percentage of MgO may be as much as 9%, but it rarely exceeds 7%. Biotites from the pegmatitic facies are apparently richer in either ferric or ferrous iron than those from the plutonic rocks, but biotites from the equivalent extrusive rocks appear to be much richer in MgO.

BIOTITES FROM GNEISSES AND SCHISTS.

Despite the variation in mineral content and texture of metamorphic rocks, most of these biotites have a closely restricted range in chemical composition (Fig. 7). The FeO maximum is 20%; Fe_2O_3 is generally less than 10%; and MgO is commonly less than 18%. The field occupied by this group includes

the area occupied by the intermediate group (Fig. 3) but extends beyond it toward the field of the gabbroic biotites. Although both ortho- and paragneisses are included in the group, the biotites show no extreme variations in composition. A few biotites from amphibolites were plotted and fell into the area of the ultramafic biotites.

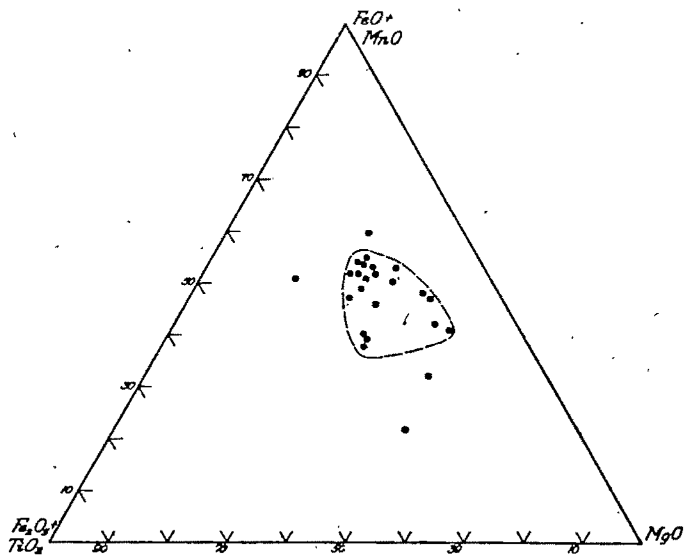

Fig. 7. Biotites from Gneisses and Schists.

PHLOGOPITES FROM METAMORPHOSED LIMESTONES.

The micas that occur in metamorphosed limestones are phlogopites very rich in magnesium with a maximum MgO content of about 30% (Fig. 8). Many of these contain very little iron, and the maximum content of the two iron oxides is less than 10%. A special group that is not plotted on the triangular diagrams is the manganophyllite sub-series, which includes the magnesium-manganese micas that are generally low in iron. These contain a maximum of 12% $MnO+Mn_2O_3$.

BIOTITES FROM PEGMATITIC FACIES.

The diagrams indicate that biotites from pegmatitic facies in the granitic and syenitic groups are richer in iron than those from the plutonic equivalents. In the other intrusive groups

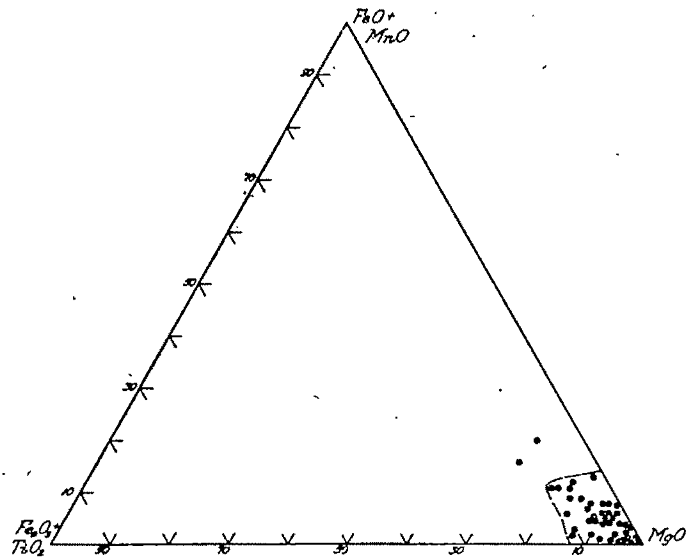

Fig. 8. Phlogopites from Metamorphosed Limestones.

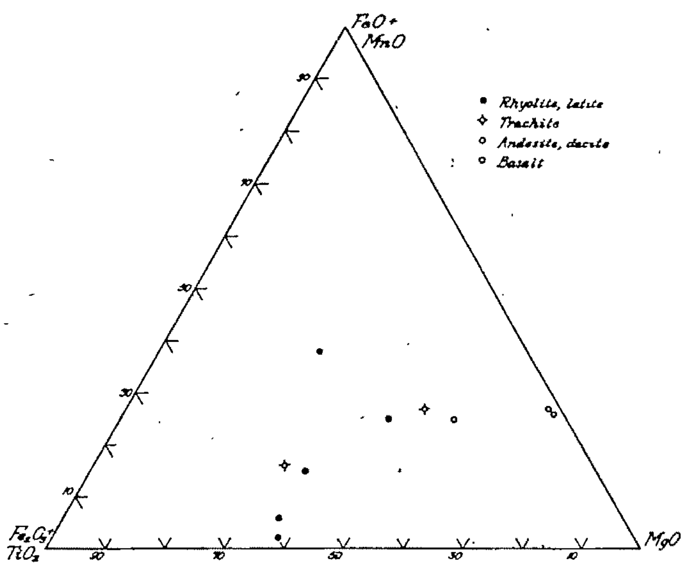

Fig. 9. Biotites from Extrusive Rocks.

the meager data that are available indicate that this relationship is probably also valid. Rubidium- and caesium-bearing biotites are known only from pegmatites.

BIOTITES FROM EXTRUSIVE ROCKS.

Except for basaltic biotites, the extrusive ones do not fit at all well the fields of their intrusive equivalents. Not enough analyses are available for a complete picture of the relationships between the two, but in general the extrusive ones are poorer in FeO. Biotites rich in $Fe_2O_3+TiO_2$ and with moderate amounts of MgO appear to be restricted to extrusive rocks (Fig. 9). In many of the extrusives the analyzed biotite occurs as phenocrysts, which may not have attained chemical equilibrium with the groundmass. Also oxidation of some of the iron to the ferric state may have taken place.

RELATION OF INDEX OF REFRACTION TO CHEMICAL COMPOSITION.

Several attempts have been made to show in a quantitative way the relation between the indices of refraction and the chemical composition of biotites (Grout, 1924; Kunitz, 1924; Winchell, 1935; Kunitz, 1936; and Hall, 1941). Grout plotted α and γ against the combined weight percentage of FeO and Fe_2O_3 and obtained a curve with a uniform slope up to about 28% of the oxides, after which point the curve flattens slightly. Twelve analyses were used. Kunitz plotted α against the weight percentages of the two theoretical "end-molecules," $K_2HAlMg(SiO_4)_3$ and $KH_2AlFe_3(SiO_4)_3$, and obtained a straight line with seven analyses.

The theoretical "end-molecules" used by Kunitz (1924) and Winchell (1935) have little significance in the structure of the biotite molecule, nor can the variation in chemical composition of the series be expressed adequately in terms of them. Kunitz (1936) showed that in those biotites in which the total iron remains nearly constant the index of refraction increases with increasing titania, a relationship which can be expressed as a straight line function. Hall (1941) calculated that 1% TiO_2 increases the refractive index by .0046. Hall plotted also γ against weight percent FeO and obtained two general fields, one of which (Field 1) contained the iron-titanium biotites and the other (Field 2) with lower indices which contained the iron-manganese biotites.

The writer plotted the γ indices of refraction of about 60 biotites and phlogopites against the weight percentages of

$FeO+Fe_2O_3$, but no simple relationship was evident. Next the indices were plotted against the weight percentages of MgO, but this result was even less satisfactory. A third trial consisted of plotting the indices on a triangular diagram of the type employed in Figures 1-9 and then contouring the result, but this scheme was unsuccessful.

A fairly well defined curve was obtained by plotting the indices against the combined weight percentages of FeO, Fe_2O_3, and TiO_2. This had the advantage of throwing nearer to the line many of the analyses in which Fe_2O_3 is low, for it is in these biotites that the higher percentages of TiO_2 occur. In

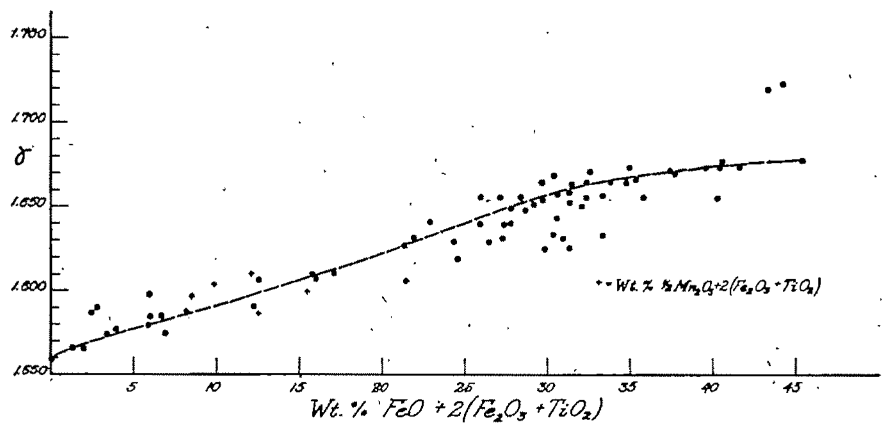

Fig. 10. The Relationship between Index of Refraction and Chemical Composition in the Biotite-Phlogopite Series.

general, however, the curve was unsatisfactory, especially for the biotites unusually rich in ferric iron.

It is likely that increments of Fe_2O_3 and TiO_2 have a greater effect upon the indices than have comparable additions of FeO. To test this idea the weight percentages of Fe_2O_3, and TiO_2 were weighted by various numbers. The best curve was obtained when a factor of 2 was used (Fig. 10). Thus it appears that the effect of the ferric iron and the titanium is about twice that of the ferrous iron. The γ indices of a few manganophyllites were also plotted against $\frac{1}{2}(Mn_2O_3 \text{ or } MnO)+2(Fe_2O_3+TiO_2)$. These plots fall reasonably close to the curve and indicate that the effect of the manganese is less than that of the ferrous iron.

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THE PRINCIPAL THESES OF THE GENETIC SYSTEMATICS OF INTRUSIVE BODIES.

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1. The genetic systematics of intrusive bodies may be based on the following principal thesis: "Every intrusive body, as a whole, represents a state of equilibrium existing between the endogenic forces of the active magma on the one hand and the tectonics and kinematics of its enclosing frame on the other. The internal structure of every intrusive body is controlled by the relation between the period of the crystallization of the magma and that of its endogenic kinematics, as well as by the synchronous kinematics of the frame." This principal thesis modifies and expands the thesis previously advanced by H. Cloos (1936).[1]

The factors contained in the first part of the newly advanced thesis determine the principal geological features peculiar to intrusive bodies. The rôle of the activities displayed by subcrustal and intracrustal magma will now be severally discussed.

2. The active forces of subcrustal magma take part in stimulating the kinematics of the earth's crust, and, consequently, in determining its tectonics, as well as in evoking magmatic activity. The active forces of intracrustal magma are made manifest: a) in the chemical effect produced on the formation of the frame, which is controlled by physical-chemical laws (migmatite- and migma-plutons); b) in the vertical movement of the magmatic column, due to gravitation (migma-, and diapir-plutons); c) in the hydrostatic pressure caused by the column of rising magma (central subvulcanoes, diapir dykes, sills, laccoliths, bysmaliths, lopoliths in part, interformational chonoliths, etc.); d) in the action caused by changes of phase-equilibrium in the gaseous-liquid magma (diatremes, necks). Hence four genetic types of intrusive bodies can be distinguished.

3. The two-story, or many-story cratogenic and orogenic structures in the earth's crust (I. supracrustal formations, II., III . . . basement) are in themselves an armor almost impene-

[1] Cloos, H.: 1936, Einführung in die Geologie, p. 75.

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trable by the magma, but within them there are several directions favorable to the distribution and spreading of the magma (the anisotropic structures of rocks, the boundaries of layers and formations, stratigraphic and tectonic disconformities). The impenetrability of the cratogenic and orogenic structures of the earth's crust can be overcome only by its kinematics and by the active forces of the magma. The latter are modified by the different tectonics and kinematics of the frame. Hence two principal groups of intrusions—those in cratogenic regions and those in orogenic regions—should be distinguished.

4. There are no less than four types of kinematics peculiar to the cratogenic regions of the earth's crust, which are accompanied by magmatic activity: fractures a) of regional faults (Africa); b) of gigantic folds (the Rhine elevation); c) of the Moore-Cloos type (the Caledonian foreland in Sweden and the Kola Peninsula); d) of tangential flexures (Oslo, the Kola Peninsula). Accordingly, the following types of intrusions are found to occur in the one- and two-story cratogenic structures: a) joint instrusive bodies, which are synkinematic with the fracture of four genetic types, in which the frame is mostly passive (extension of earth's crust) and less frequently active (compression of the earth's crust), and b) intrusions connected with the effect produced by the active magma (for the most part those of type 2 b, c).

5. Three types of intrusions—pre-orogenic, synorogenic, and apo-orogenic—can be distinguished according to the different tectonics and kinematics of the earth's crust in orogenic regions. In the pre-orogenic period the structure and kinematics of the earth's crust in orogenic belts—both in those belts that had and those that had no preparatory geosynclinal stage—are very much alike and also closely resemble those in cratogenic regions, differing from each other in the thickness of supracrustal formations and in the amplitude of the vertical movements. Accordingly, the pre-orogenic intrusions in these regions are like those in cratogenic regions (dikes, sills, laccoliths, etc.). In the synorogenic period, in accordance with the differing tectonics and kinematics the intrusive bodies in the orogenic regions are also different: a) depending on whether they had a preparatory geosynclinal stage or b) they had a geosynclinal preparation. In the first case (a) the formations of the basement are limited in their plastic deformation and disrupt in longitudinal fractures, along which the kinematics

of several hard blocks are found to occur. In contrast to this, the supracrustal formations are subjected to folding, plastic deformation, fractures and thrusts in which the blocks of the basement also take part. In case of intrusive activity the magma penetrates into the lower story along the fractures, and if its mass is small the movement and distribution of magma is controlled by the kinematics of the hard blocks, and at a higher level by the kinematics of the plastic deformation in the supracrustal formations. Here the effects of magma activity are limited, but are found to increase as its mass grows in volume, reaching particular importance where the magma spreads along the boundary of disconformity between the supracrustal formations and the basement (plutons of the west European Variscides). In the second case (b), owing to the development of ultrametamorphism, universal plastic deformation is found to occur in both stories and the boundary between them is effaced. Small masses of magma on being subjected to the universal kinematics of the frame, also take part in its movement, migrate, and undergo considerable deformation, which is the greater, the less yielding the plastic rocks of the frame are. Only large masses of magma are able by their movement to affect the nature and direction of the kinematics of the frame. Thus conformable and accordant intrusions of ophiolites proper of island arcs, basic magma, and granodiorites are found to originate, sometimes forming phacoliths, which are situated not only in geosynclinal troughs, but also penetrate into the overthrust sheets (Scandinavia). Ultrametamorphism results in granitization and in the development of synkinematic migmatite-plutons, then later of longitudinal migma-plutons, and finally, of diapir-plutons, because the chemical activity of the magma is effective first and later is followed by the action of gravitational forces. However, under conditions of ultrametamorphism as well, the unequal plasticity of the rocks causes the development of boudinage structures and feather joints, within which "interboudinage-plutons" and veins of feather joint-type are formed and filled with secretional magma. Here likewise "dead" boudinage-plutons are formed of pre-orogenic magmatic bodies.

6. Under apo-orogenic conditions the impenetrability of the earth's crust in orogenic belts is disturbed by another type of kinematics, i.e., fractures that accompany the formation of gigantic folds, or the phenomenon of epeirophoresis. In the

first case the kinematics of the earth's crust is similar to that of cratogenic regions, and their intrusions are therefore very much alike, differing only in the modification of magmatic activity by the more complex tectonics inherited from the synorogenic period. In the second case disconformable cross-cutting intrusive bodies are formed, in which the magma has crystallized under conditions in which the frame was relatively passive, or in contrast to this, others in which the distribution of the magma is controlled by the kinematics of the frame and by the increased activity of the magma in the upward direction. Hence in a number of cases these latter intrusions are similar to those of cratogenic regions.

7. The above stated data show that such factors as the activity of the magma and the tectonics and kinematics of the frame may serve as basis for the classification of intrusive bodies. Only the above-suggested principal division makes it possible further to distinguish and characterize intrusions according to: a) their distribution in the different stories and structures of cratogenic and orogenic regions; b) the relation between their boundaries and the structures of the frame; c) their shape; d) their relative size; e) the geological importance of the totality of certain types of intrusions among the total number of other types of the same geological cycle.

8. The division of intrusions according to their inner nature and structure can be made by introducing the well known criteria, namely those of "pluton" and "subvulcanic." Among these in turn, monophase, multiphase-multiple, and composite intrusive bodies should be distinguished. Finally, to each intrusive phase the second part of the previously cited thesis (§ I) should be applied. This will permit us finally to divide and characterize every type of intrusion, for it determines the evolution of the textural and structural facies of rocks, the types of teleo-structures of intrusive bodies, partly the kinds of differentiation processes that took place in situ and even the types of endogenic and exogenic joint tectonics. This final characterization and subdivision of all intrusive masses can be formulated as follows:

9. According to their mode of evolution intrusive bodies may be I, primary precrystalline and II, primary paracrystalline. The first type (I), the primary precrystalline intrusions, in which movement of the magma preceded crystallization (apoendokinetic crystallization) while the frame remained pas-

sive, shows a normal granitic textural character. It may be divided into subtype A, non-differentiated intrusions, having an isotropic rock structure and, consequently a teleo-isotropic geological structure, and subtype B, differentiated intrusions, having an anisotropic rock structure and a teleo-anisotropic geological structure. According to the arrangement of teleo-anisotropism, we may distinguish conformable, non-autonomous intrusions (a vast number of sills, etc.), and disconformable autonomous intrusions. The joint tectonics of type I is linked only with the phenomena of contraction during cooling.

Type II, primary paracrystalline intrusions, in which crystallization was followed by movement of the magma (synkinematic crystallization) may likewise be divided into two subtypes A and B. Subtype A, is termed an endosynkinematic intrusion owing to the passivity of the frame; it has a granitic or a gneissose texture (at the margin of the intrusion). In this case the structures of the rocks are invariably anisotropic, and therefore intrusive bodies are teleo-anisotropic. They can be further divided into groups of non-autonomous (non-viscose magma) and autonomous (viscose magma) intrusions, which in turn may be either differentiated or non-differentiated, and, finally, these can be further distinguished according to their internal structure (teleodome-like, teleospheroidal-shlieric). The joint tectonics of subtype A is endosynkinetic (partly the proper granitic tectonics of H. Cloos). Subtype B is called pansynkinetic, because crystallization occurred simultaneously with the movement of the magma and of the frame. The resulting rocks have invariably gneissose structure with anisotropic structures. The intrusive bodies may be teleo-anisotropic-autonomous (less frequently) and non-autonomic-conformable and each of them may be differentiated (the types of differentiation) and non-differentiated. The joint tectonics is endo- or exosynkinetic.

10. Finally, if a solidified "dead" intrusive body is newly subjected to the action of the kinematics of its frame, this renewed movement causes the intrusive body to be deformed and disrupted by fractures, faults, zones of tectonites, and boudinage structures, which may or may not be accompanied by pre-, para-, or postcrystalline recrystallization, resulting in the formation of various metamorphic facies of rocks. There are pre-, para-, and postcrystalline "dead," or "metaintrusive" bodies.

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THE ORDOVICIAN TRILOBITE DIMEROPYGE.

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ABSTRACT. *Dimeropyge* occurs in Middle and Upper (?) Ordovician rocks of Europe and America. A Canadian species is redescribed, two new species are defined, and the other four species are noted.

INTRODUCTION.

THE genus *Haploconus* was erected by Raymond (1913, p. 61) for trilobites "related to *Cyphaspis*, but differing in not having isolated basal lobes on the glabella, and in having a less prominent axial lobe on the pygidium." *Bathyurus smithii* Billings, which had described from a fragmentary cranidium, was taken as a genotype. Raymond described and referred to *H. smithi* the only complete specimen known. Unfortunately the reproduction of his figures was poor, and the genus has been confusing to later workers. Thus Warburg (1925, p. 199) suggested that it might be a synonym of Törnquistia Reed (1896, p. 435), and Öpik (1937, p. 32) was misled into comparing with it a pygidium of quite different aspect, and described its true pygidium under a new name.

Since the name *Haploconus* was used earlier by Cope for a mammal tooth (1882, p. 417), Öpik's name is available for the trilobite which should be called *Dimeropyge*.

My notes are based on specimens in the collections of the Geological Survey, Canada, and I am grateful to Dr. W. A. Bell, Chief of the Survey's Palaeontological Division, for permission to study them. Dr. R. Darnley Gibbs of McGill University has kindly made the photographs of these minute fossils.

THE GENOTYPE.

Öpik (1937, p. 32, pl. 12, figs. 1-2; pl. 4, fig. 5; pl. 19, fig. 1) described a small pygidium as *Dimeropyge minuta*, new genus and species. He was doubtful of its relationships, and suggested among other possibilities that it might belong to the cranidia which he described as *Törnquistia ? minuta* (Nieszkowski) (pp. 29-31, pl. 2, figs. 3-6; pl. 3, figs. 1-2; not pl. 4,

figs. 1, 2, 6).[1] The Canadian specimens show that this is the correct association, and that the species belongs to the genus for which Raymond had proposed the unavailable name *Haploconus*. The genotype then is *Dimeropyge minuta* (Nieszkowski 1857), described originally as *Sphaerexochus minutus*, and sometimes referred to *Menocephalus*. The species is said to be frequent in the Kukruse beds (C2) of Esthonia. The most striking difference from the American species is the lack of the post-rhachial piece in the pygidium, but the pygidium is known in only two of the latter. Neither of these two species shows nodes on the pygidium, but they are present on the thorax of *D. gibbus*.

Description of Canadian Species.

Dimeropyge smithii (Billings).

(Plate 1, figure 7).

Bathyurus smithii Billings, 1862, p. 56.
Billings, 1863, p. 153, fig. 114a.

The type and only known specimen is a poorly preserved partial cranidium, consisting of the glabella and most of the fixed cheeks. Glabella convex, narrowing forward, broadly rounded in front, surrounded by a deep furrow; no glabellar furrows seen. Fixed cheeks convex, uniting in front as a preglabellar field which is bent down gently. Palpebral lobes narrow, rather long. Occipital furrow strong both on the cheeks and mesially. Neck-ring long, with a minute median tubercle. Surface, anterior margin and free cheeks unknown.

As preserved the specimen is 2.3 mm. long, about 3.2 mm. wide; glabella 1.6 mm. long, 1.3 mm. wide behind; neck-ring .4 mm. long.

Holotype: Geological Survey, Canada, 1818. Collected by J. F. Smith.

Horizon: Black River Group.

Locality: Peterborough, Ontario.

Remarks: This species differs from *O. gibbus* in the slight

[1] This relationship was also suggested by Thorslund (1940, Sveriges geol. Undersokning, C 436, p. 152), who described an allied species as "*Tornquistia ? parvula*." The course of the facial sutures, the presence of spines on the anterior margin and the spinose thorax seem to remove the species from *Dimeropyge*.

flexure of the pre-glabellar field, and in the proportionately longer glabella. Its proportions are very close to those of *D. lucifer*, but it is less convex and apparently lacks the glabellar furrows.

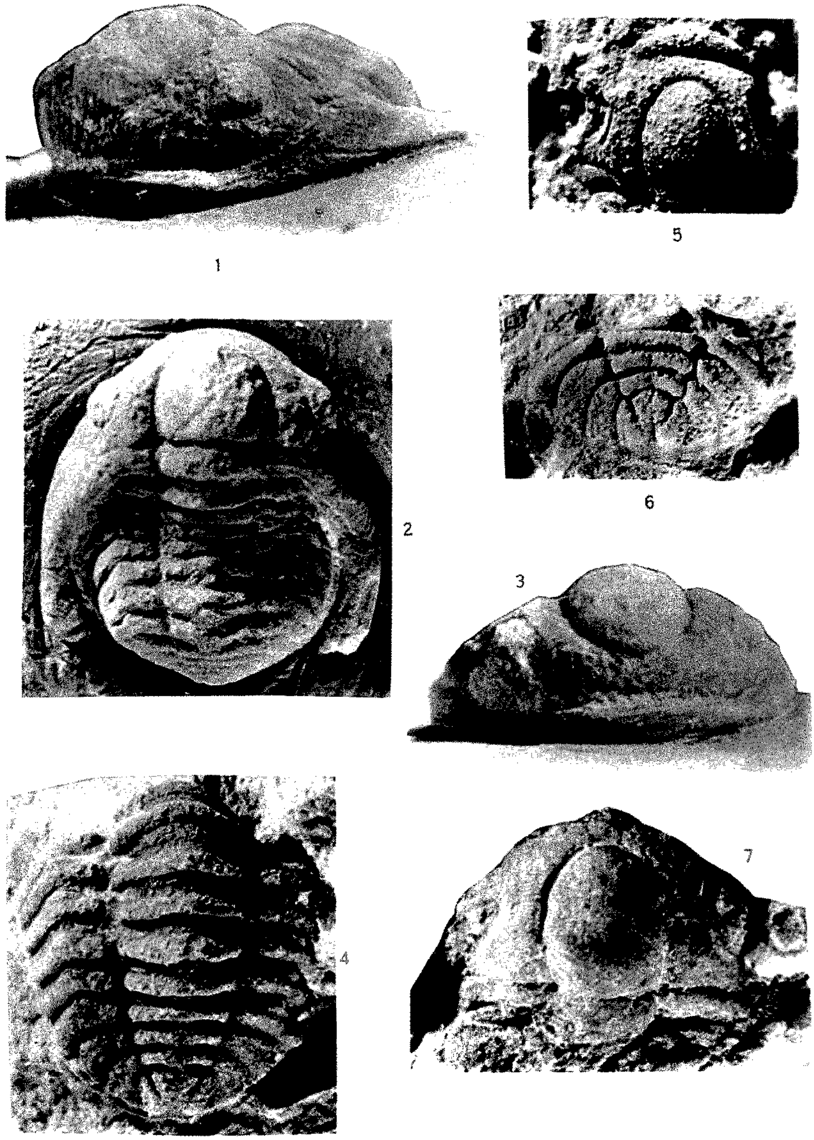
I have accepted Billings' horizon here, although Raymond gives the species as occurring only in the Middle Trenton, apparently assuming an error in labelling. I am not sure that the matter is so simple. Billings knew that Trenton limestone outcrops at Peterborough, indeed he described a fossil from it on the page preceding the description of *Bathyurus smithii*. It would seem, therefore, that he had some reason for believing the age of the trilobite to be different. Smith was not a casual collector, but himself published notes on trilobites. At this time E. J. Chapman was active in Toronto, describing Peterborough fossils and writing copiously on trilobites. It seems strange that the published horizon should go uncorrected were it wrong. I think it more probable that the locality should be taken as "near Peterborough," although this can not be settled. There is not sufficient matrix with the specimen to help in deciding the question. This discussion has point since Billings' specimen and the complete specimen from the Peterborough Trenton later referred to the species by Raymond differ considerably, and I do not believe that they can be included in one species.

Dimeropyge gibbus new species.

(Plate 1, figures 1-4).

Haploconus smithii Raymond (not Billings), 1913, p. 62, pl. vii, figs. 13-14.

The specimen described by Raymond is very small, the surface is poorly preserved, and parts of the head have been marred by tool marks. However it is possible to add something to his description. The pre-glabellar field is perpendicular to the plane of the head, as is the anterior border. The latter is not "upturned," although it projects slightly beyond the field. The free cheeks fall off very steeply, almost vertically, at the sides. The eyes are subcircular and prominent. Palpebral lobes are narrow, separated from the fixed cheeks by shallow grooves. I must disagree with Raymond's interpretation of the facial suture. Behind, it cuts the posterior margin



EXPLANATION OF PLATE I

All figures are approximately 12 times natural size.

Figures 1–4. *Dimeropyge gibbus* Sinclair. 1–3, the holotype in various aspects. The genal spines appear thicker than they are because all the matrix has not been removed from their inner edges. Sherman Fall limestone: Peterborough, Ontario. Geological Survey, Canada (GSC) 7828. 4, paratype pygidium and thorax. Sherman Fall limestone: Lakefield, Ontario. GSC 6701.

Figures 5–6. *Dimeropyge lucifer* Sinclair. 5, holotype cranidium, GSC 6726. 6, paratype pygidium, GSC 6726a. Both from Middle Trenton rocks: Roberval, Quebec.

Figure 7. *Dimeropyge smithii* (Billings). Holotype, a partial cranidium. Black River group: Peterborough, Ontario. GSC 1318.

just within the inner edge of the genal spine, then crosses the cheek obliquely to the eye. From the eye it runs forward to the marginal groove, but then turns sharply in across the border to cut the anterior margin almost in the mid-line.

The thorax and pygidium are seen better in a second specimen. Thoracic rhachis elevated. Pleura not grooved, horizontal for a little more than one-third their width, then bent abruptly down and back; each bears a large elevated node near the dorsal furrow. The forward edge of each pleuron has a rather large triangular projection at the point of geniculation.

Pygidium transverse, almost flat on top. Rhachis flat, wide, triangular. First ring complete, transverse, having the shape of a rod with parallel sides and bluntly rounded ends. Second ring a little interrupted in the middle by a longitudinal depression, which continues across the third ring. A triangular piece behind the third ring completes the rhachis. Furrows between the rings deep, strong, that behind the third ring a little shallower. Pleura moderately convex on top, the inner ends of the ribs at the dorsal furrows higher than the rhachis. First pair of ribs subequal to the first ring in width, bent a little back, ending distally in a prominent projection a little above and beyond the general surface; bordered in front by a lower triangular process with straight edges, the front edge transverse, the lateral edge inclined at 110° to it. Then follow two pairs of rather broad, flat, almost smooth ribs, separated by weak furrows, ornamented by sparse granules distally. Between the last ribs, on either side of the post-rhachial piece, are two small areas which are sharply separated behind, and which end in prominent knob-like projections. The whole pygidium behind the first ribs is bordered by a concave, almost vertical, margin which bears a single row of large, very indefinitely defined, subcircular depressions, corresponding more or less to the second and third ribs and the furrows between them. The lower edge of the border is finely granulose.

Dimensions of complete specimen (holotype): 4.4 mm. long, 4.3 mm. wide, cephalon 1.75 mm. long, glabella 1.25 mm. long, 1.2 mm. wide, pre-glabellar field 0.5 mm. high; convexity of head 2 mm. Of paratype: five thoracic segments 2.5 mm. long, 3.6 mm. wide; rhachis 1.6 mm. wide in front; pygidium 1.5 mm. long, 3 mm. wide, rhachis 1.2 mm. wide in front.

Types: Geological Survey, Canada, holotype 7828, paratype 6701. Collected by L.M. Lambe and by the writer.

Horizon: Trenton group, Sherman Fall formation.

Localities: Peterborough (holotype) and Lakefield (paratype), Ontario, Canada.

Dimeropyge lucifer new species.

(Plate 1, figures 5 and 6).

Cranidium small, convex. Glabella short, conical, strongly and evenly convex, with three pairs of short, rather shallow but distinct, equidistant furrows; the first pair opposite the back of the eye, the middle pair almost at the front of the eye, the third far forward on the antero-lateral curve of the glabella; the furrows are transverse or directed a little back; the middle pair is the longest. Neck-ring long, convex. Fixed cheeks convex, falling sharply, almost vertically, to the postero-lateral corners. Posterior marginal furrow strong, transverse; the posterior margin runs a little back, so that the border widens distally. Palpebral lobe narrow, much lower than the adjacent surface of the cheek, set off by a rather strong furrow. Preglabellar field convex, just a little off the horizontal. Anterior marginal furrow very strong. Border wide, slightly convex, horizontal, truncated in front by the oblique sutures. Surface rather coarsely pustulose throughout.

Free cheeks and thorax not known.

Pygidium very similar to that of *D. gibbus*, but the rhachial rings are wider and flatter, the third ring is distinctly bent instead of being transverse; the pleural ribs are less pustulose, and the first rib is more elevated above the anterior projection.

Holotype cranidium: 2.1 mm. long, 3.2 mm. wide; glabella 1.2 mm. long, 1.0 mm. wide; neck-ring 0.3 mm. long; anterior border 0.3 mm. long; convexity of cranidium 0.85 mm. Paratype pygidium: 1.6 mm. long, 2.8 mm. wide, rhachis 1.1. mm. wide in front.

Types: Geological Survey, Canada, holotype 6726, paratype 6726a. Collected by the writer.

Horizon: An unnamed limestone of Middle Trenton age.

Locality: One mile north of Roberval, Lake St. John county, Quebec.

Remarks: This species is most similar to *D. tumidus* but has distinct glabellar furrows. The glabella is longer than that of *D. gibbus*, and the attitude of the pre-glabellar field is quite different. The poor preservation of *D. smithii* makes compari-

son difficult, but the glabella of *D. lucifer* is more convex, and the neck-ring lacks any trace of a median pustule.

The anterior marginal furrow in this species is so deep that most specimens have broken along it, so that the cranidia lack the border. This seems to have happened in other species, in which the border has not been seen.

Other Species.

Dimeropyge galenensis (Clarke) (1894, p. 759, fig. 82). Prosser member of Galena formation; Cannon Falls, Minnesota (horizon from Stauffer and Theil 1941, p. 234). This species, which was referred to *Haploconus* by Raymond, is still imperfectly known. The glabella tapers less, and the fixed cheeks are wider in front, than in the Canadian species.

Dimeropyge tumidus (Bradley) (1930, p. 263, pl. 29, figs. 28-29). Kimmswick limestone; Missouri and Illinois. Bradley recognized the true course of the facial suture in the cranidia which he described. The species is very similar to *D. lucifer*, but lacks the glabellar furrows.

Dimeropyge raymondi (Roy) (1941, p. 154, fig. 113). "Richmond"; Frobisher Bay, Baffin Land. Roy described this species as *Ischyrotoma ? raymondi*, but it seems to belong here. The species is comparable with *D. lucifer*, and like many specimens of that species Roy's type seems to have lost the anterior border. It is twice the size of the Trenton species and the glabella is a little longer. There seem to be two pairs (not one pair, as in Roy's description) of glabellar furrows, which seem to be directed a little more back than in *D. lucifer*.

Cyphaspis ? brevimarginatus Walcott (1884, p. 93, pl. 12, fig. 10) was referred to *Haploconus* by Raymond, but from the description it seems to be very different, and I do not include it here even tentatively.

Summary.

Dimeropyge (synonym *Haploconus* Raymond, *non* Cope) is a genus of small opisthoparian trilobites characterized by very convex cephala, short convex glabellae with furrows lacking or poorly developed, convex fixed cheeks forming a wide preglabellar field in front, long genal spines, and facial sutures which cut in across the anterior border to end almost in the mid-line. The pygidium is wide and flat, the rhachis quite flat

with three rings the pleura with three pairs of wide ribs, the whole with a steep border. The genus is known from the Middle and Upper (?) Ordovician of Esthonia (one species) and North America (five species).

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DISCUSSION.

GLACIAL CLIMATES IN THE SOUTHERN HEMISPHERE.

Among the valuable reports on Sir Douglas Mawson's Australasian Antarctic Expedition of 1911-1914, which have been appearing at intervals during the past few years is a meteorologic report of interest to geologists.[1] It is an excellent description (unfortunately posthumous) of Antarctic climate, based on studies made at three localities. The author, Dr. Edward Kidson, lately Director of the Meteorological Office of New Zealand, was an able terrestrial physicist. He had earlier studied and published the meteorologic results of the Shackleton Expedition of 1907-09. During this time he twice visited Europe and North America in order to discuss with other students of polar meteorology some of the outstanding problems of polar climates.

In the present work the author has implied that the Antarctic Ice Sheet is nourished by relatively warm moist air masses that surmount the ice after approaching it from lower latitudes. This implication is parallel with recent findings on the Greenland Ice Sheet, ably summarized by Matthes,[2] which refute repeated assertions by Hobbs that the Greenland ice is nourished by an "anticyclone."

On certain assumptions as to relative humidity and other factors, Kidson has calculated that the Antarctic Ice Sheet would receive annually about 3.6 inches of precipitation expressed as water. This precipitation is believed to occur chiefly in the outer or peripheral belt, with very little in the central area near the Pole.

Sir G. C. Simpson argued that extensive glaciation during the Pleistocene was caused chiefly by increase in precipitation rather than by decrease of temperature, and that the increased precipitation resulted from an increase of temperature. Kidson, however, has concluded that the observed present and inferred former glacial conditions in the high-latitude regions of the southern hemisphere do not support Simpson's contention, for both the existing glaciers and the former glaciation of these lands are related to low mean temperatures rather than to high precipitation—or, rather, to a combination of low temperatures and at least moderate precipitation.

[1] Edward Kidson: 1946, Discussions of observations at Adélie Land, Queen Mary Land and Macquarie Island. Australian Antarctic Expedition 1911-14, Sci. Rps., ser. B, 6: Meteorology, 121 pages. Sydney, Australia.

[2] Matthes, François E.: 1946, The glacial anticyclone theory examined in the light of recent meteorological data from Greenland, Part I. Am. Geophys. Union, Trans., 27, 324-341.

". . . so long as the precipitation exceeds a certain value, which doubtless varies inversely as the latitude, the degree of glaciation appears to depend almost entirely on the temperature."[3] Kidson has added his conviction that "a marked fall of temperature would be necessary to produce the conditions at the maxima of glaciation in Pleistocene times."[4]

The Antarctic Continent presents a special problem because there the temperature is perennially below the freezing point. Scott and others since his time have expressed the thought that the ice sheet could expand only as a consequence of a rise in temperature, which would increase the annual precipitation. Kidson has deduced that such an increase in temperature and precipitation would reduce the amount of sea ice off the Antarctic coast, increase the katabatic winds that flow off the ice sheet, and increase the rate of ablation. If, on the contrary, the temperature were to be reduced, the sea ice would increase and ablation would diminish; this might lead to slow expansion of the ice sheet despite reduced precipitation. Kidson believed we lack adequate data for deducing the net effect of these changes; in his opinion the question remains open.

This report also deals with the hypothesis propounded by Milankovitch[5] and others, that the glacial ages were brought about by several periodic changes in the relation of Earth to Sun. In so far as it applies to the southern half of the southern hemisphere this hypothesis is rejected, mainly on the chief ground on which it was rejected by Simpson,[6] namely, that it is quantitatively inadequate.

Kidson's conclusion is that meteorologists must find some better cause of the glacial climates of the Pleistocene—a cause more nearly in accord with the facts of geology.

RICHARD FOSTER FLINT.

[3] Kidson, p. 117.

[4] Kidson, p. 117.

[5] Milankovitch, Milutin: 1930, Mathematische Klimalehre und astronomische Theorie der Klimaschwankungen. *In* Köppen, W., and Geiger, R., Handbuch der Klimatologie, 1, pt. A, Berlin, 176 pages.

[6] Simpson, G. C.: 1940, Possible causes of change in climate and their limitations. Linnean Soc., London, Pr., 152, 190-209.

SCIENTIFIC INTELLIGENCE

CHEMISTRY.

Catalytic Chemistry; by HENRY WILLIAM LOHSE, Pp. xiv, 471. New York, 1945 (Chemical Publishing Co., Inc. $8.50). In his preface the Author states "In writing this book, I have aimed at a brief factual presentation of the underlying principles of catalytic phenomena and the application of catalytic reactions in industrial processing. In many cases, no attempt has been made to modify the original author's view, although such a presentation may lack cohesion. This is meant to reflect the multiplicity of experience and also the variance in conception which exist in catalytic chemistry up to this time." (p.v.) The author seems to have fulfilled his purpose. The contents of the book are gathered into five chapters: I, Brief history of catalytic chemistry; II, Catalytic theory; III, Nature and properties of catalysts; IV, Specific types of catalytic reactions; V, Industrial catalytic reactions. The individual sections are too numerous to list. Chapter III surveys the elements and their compounds as used in catalysis, classifying them into groups. Chapter IV deals with types of reaction (18 types) such as oxidation, dehydrogenation, cyclization, etc., and Chapter V with the industrial uses to which these reactions are put. The book is well and adequately illustrated, and contains an abundance of references. It seems to the reviewer that this book will be useful in guiding the reader into this very complex subject.

HAROLD G. CASSIDY.

Physical Methods of Organic Chemistry, Vol. II; ED. A. WEISSBERGER. Pp. vii, 737 to 1867. New York, 1946 (Interscience Publishers, Inc. $8.50). This is the second volume in a series bearing the title "Technique of Organic Chemistry." The first volume was reviewed in this Journal 244 596 (1946). This volume is a continuation of that one, in that the pagination is continuous from it, and this volume contains a subject index for both volumes. The contents are as follows: Spectroscopy & Spectrophotometry (W. West); Colorimetry Photometric Analysis, and Fluorimetry (West); Polarimetry (W. Heller); Determination of Dipole Moments (C. P. Smyth); Conductometry (T. Shedlovsky); Potentiometry (L. Michaelis); Polarography (O. H. Müller); Determination of Magnetic Susceptibility (Michaelis); Determination of Radioactivity (W. F. Bale and J. F. Bonner, Jr.); Mass Spectrometry (D. W. Stewart). The remarks made in connection with

Volume I apply well here also. The book is, as far as the reviewer could see, relatively free from misprints and adequately illustrated. The same high quality of the contents found for the first volume is maintained here. HAROLD G. CASSIDY.

PALEONTOLOGY.

A Reexamination of the Fossil Human Skeletal Remains from Melbourne, Florida, with Further Data on the Vero Skull; by T. DALE STEWART. Smithsonian Miscellaneous Collections, vol. 106, no. 10. Pp. 28; 6 figures and 8 plates. Washington, 1946.—The discovery in 1925 of a crushed human skull in association with fossil bones of a Pleistocene fauna at Melbourne, Florida, touched off a long controversy, the paleontologists who were concerned maintaining that the skull was of the same age as the rest of the bones while most anthropologists claimed that it must have dated from Recent time. One of the more telling anthropological arguments was that the skull, as reconstructed by Aleš Hrdlička, resembled Recent rather than Pleistocene forms of man. This argument has now been refuted by T. D. Stewart, successor to Hrdlička at the United States National Museum. Making a new and apparently more accurate reconstruction of the Melbourne skull, Stewart finds that it is "not typical of the late Florida Indians" but instead fits "into our present concept of the earliest type found on the continent." Moreover, in the new reconstruction the Melbourne specimen is surprisingly similar to the Vero skull, found not far away under like circumstances. IRVING ROUSE.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

The World of Numbers; by HERBERT MCKAY. Pp. 198. Cambridge (At the University Press). New York, 1946. (The Macmillan Company, $2.50).—This book is one of the most interesting among the volumes on elementary mathematics for the general reader that have appeared in recent years. Of the sixteen chapters in which the contents have been divided, the first ten deal principally with problems that are encountered in elementary treatises on astronomy, from measuring the earth, time and planetary orbits to the sun's output of energy and stellar magnitudes. The difference from the presentation in textbooks on astronomy is that the processes of calculation are given in much detail and that the reader's interest is enhanced by witty comments and historical remarks. Among the best chapters is one that falls somewhat outside of this group: "The Arithmetic of Great Rivers" which contains a most illuminating treatment of floods and erosion.

The remainder of the volume consists of three chapters which

deal capably with the basis of calculus, the calculation of π, and with imaginary numbers, and finally three chapters on miscellaneous topics.

The author is very certain in the use of numerical data of all sorts. On this account it is regrettable that he assigns, on page 98, to Arcturus a parallax of .008″, placing the star at eleven times its true distance.

DIRK BROUWER.

Mathematical Biophysics of the Central Nervous System; by ALSTON S. HOUSEHOLDER and HERBERT D. LANDAHL. Pp. ii +, 124; 34 figs. Bloomington, Indiana, 1945. The Principia Press, Inc.)—In the introduction to *Mathematical Biophysics of the Central Nervous System,* Householder and Landahl state their aim to be "seeking to develop a theory of the nervous system as the determiner of behavior." They emphasize the fact that progress by the observational methods of anatomy and physiology is slow and present results are limited essentially to the simple spinal reflex, the paths of the retinal fibers, the mapping of several regions of the cortex, and the interaction of some regions of the cortex with others. Many details of the functioning of the neural units are known, but how, for example, the neural units are combined in the visual area to enable the organism to locate an object seen and to act accordingly is not explained by these observational techniques. It is not likely that a "wiring diagram" of the nervous system of an organism, even if it could be uniquely traced, can ever yield this type of information. Since this is a problem involving space and time intervals, a theory based on the properties of the neural elements will be required in conjunction with a "wiring diagram" in order to explain the behavior of the organism.

In this monograph such a theory is developed. Part I is concerned with idealized elementary neural units and their properties; the theory of chains of neurons, the dynamics of simple circuits, and the theory of more general neural networks. In Part II comparisons are made between the theory and experiments such as reaction times as a function of stimuli, psychophysical discrimination, and conditioning. In Part III the development of the theory from microscopic properties of the neural elements rather than the macroscopic ones used in Parts I and II is presented.

The results of the theory are two-fold. First, certain neural structures are assumed to correspond to a given class of stimuli-response behavior, and quantitative functional relations between stimulus and response are derived. The theory, if it fits in regions where data are available, can be extended to yield predictions beyond the range of verification. Second, on the basis of such analysis new experiments are suggested which are likely to be of

greater significance than the present material as more of the important factors are understood. These in turn may lead to revisions of the theory. Along these lines the book offers much promise.

Most of the mathematics used in the book is of an elementary character. A working knowledge of elementary calculus is sufficient to insure almost complete understanding of the work.

ROLAND E. MEYEROTT.

PUBLICATIONS RECENTLY RECEIVED.

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D. J. Miller, with an introduction by F. H. Moffit. Price $.15. 950. Contributions to Geochemistry 1942-45. Short papers by R. C. Wells and Others. Price $.40. Professional Papers as follows: 205-D. Late Mesozoic and Early Cenozoic History of Central Utah; by E. M. Spieker. Price $.15. 206. Upper Cretaceous Foraminifera of the Gulf Coastal Region of the United States and Adjacent Areas; by J. A. Cushman. Price $1.00. 207. Geology and Paleontology of Palos Verdes Hills, California; by W. P. Woodring, M. N. Bramlette and W. S. W. Kew. Price $1.50. 210-A. Tertiary Foraminifera from St. Croix, Virgin Islands; by J. A. Cushman with a note on the geology; by D. J. Cederstrom. Price $.20. 210-B. A Pennsylvania Florule from the Forkston Coal in the Dutch Mountain Outlier, Northeastern Pennsylvania; by C. B. Read. Price $.15. Washington, 1946.

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Communication Through the Ages; From Sign Language to Television; by A. Still. New York, 1946 (Murray Hill Books, $2.75).

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INDEX TO VOLUME 244*

* This index contains the General Heads Geochemistry, Geology, Geophysics, Mineralogy, Paleontology and Physics; under each the titles referring thereto are included. Initial capitals are in general used for the title of books noticed.

G

GEOCHEMISTRY.

GEOLOGY.

GEOPHYSICS.

G continued.

H

PHYSICS

P Continued.

Q

R

S

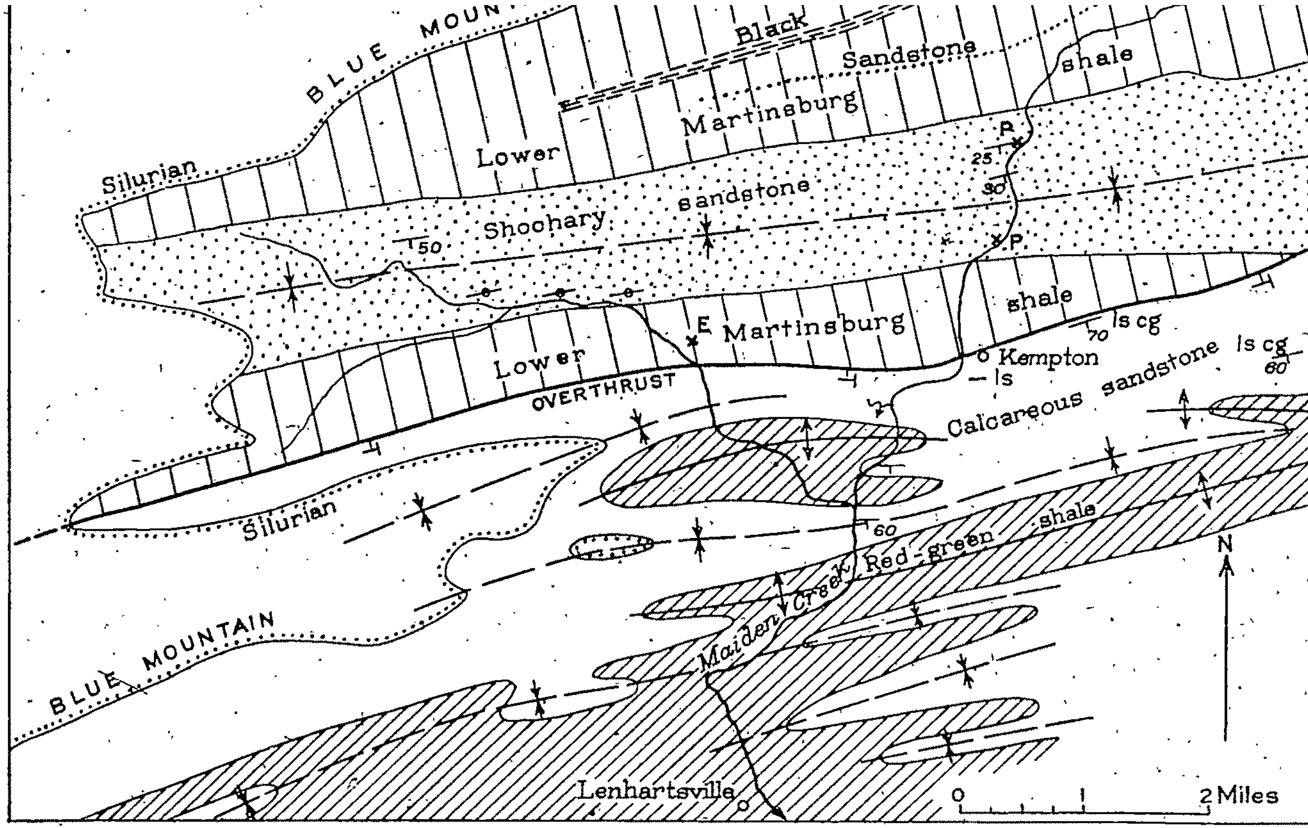

Fig. 8. Map showing relations near Kempton, Pa. North of Kempton, an open syncline encloses Shochary sandstone, the upper part of the Martinsburg shale. South of Kempton, calcareous sandstone and limestone conglomerate and red and green shale of the "Taconic sequence" are closely folded. The fault between these two sequences passes through Kempton and at Blue Mountain is overlapped by Silurian rocks.